PB-227 856

MINE DRAINAGE IN THE NORTH BRANCH POTOMAC RIVER BASIN

Leo J. Clark

Federal Water Pollution Control Administration
Annapolis, Maryland

August 1969

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PB 227 856

Chesapeake Technical Support Laboratory
Middle Atlantic Region
Federal Water Pollution Control Administration
U. S. Department of the Interior

Technical Report No. 13

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FOREWORD

In north central West Virginia near the extreme southwestern corner of Maryland's panhandle the casual visitor may come upon the Fairfax Stone, the historic marker identifying the source of the Potomac River. To a visitor observing the silvery trickle sparkling amid sylvan surroundings, it would appear that little change had occurred since the area was first surveyed by George Washington for Thomas, Lord Fairfax, in the middle of the eighteenth century.

But not for long! A few miles downstream the first evidence of coal mining activities appears. Both active and long abandoned open strip mines with the attendant scarred landscape, refuse piles, and tailings that accumulated over the past 150 years contribute acid drainage and surface leaching to the stream, discoloring it with iron and sulfur compounds, clogging the bottom with silt and coal fines and rendering it sterile and devoid of fish, aquatic plant and animal life.

Indifference to the degradation of the North Branch Potomac River and its surroundings during the past century was partly the result of its remote location, partly the lack of techniques in treating mine drainage, and partly the high cost of preventing the discharges, disposal of coal wastes and restoration of the ravaged landscape.

Water quality surveys to identify watersheds receiving the bulk of mine drainage and their effects on the North Branch Potomac River have been evaluated and are presented in this report. Corrective action will require identification of all individual mine drainage discharges in the area and development of feasible methods of eliminating or controlling the harmful aspects of mine drainage.

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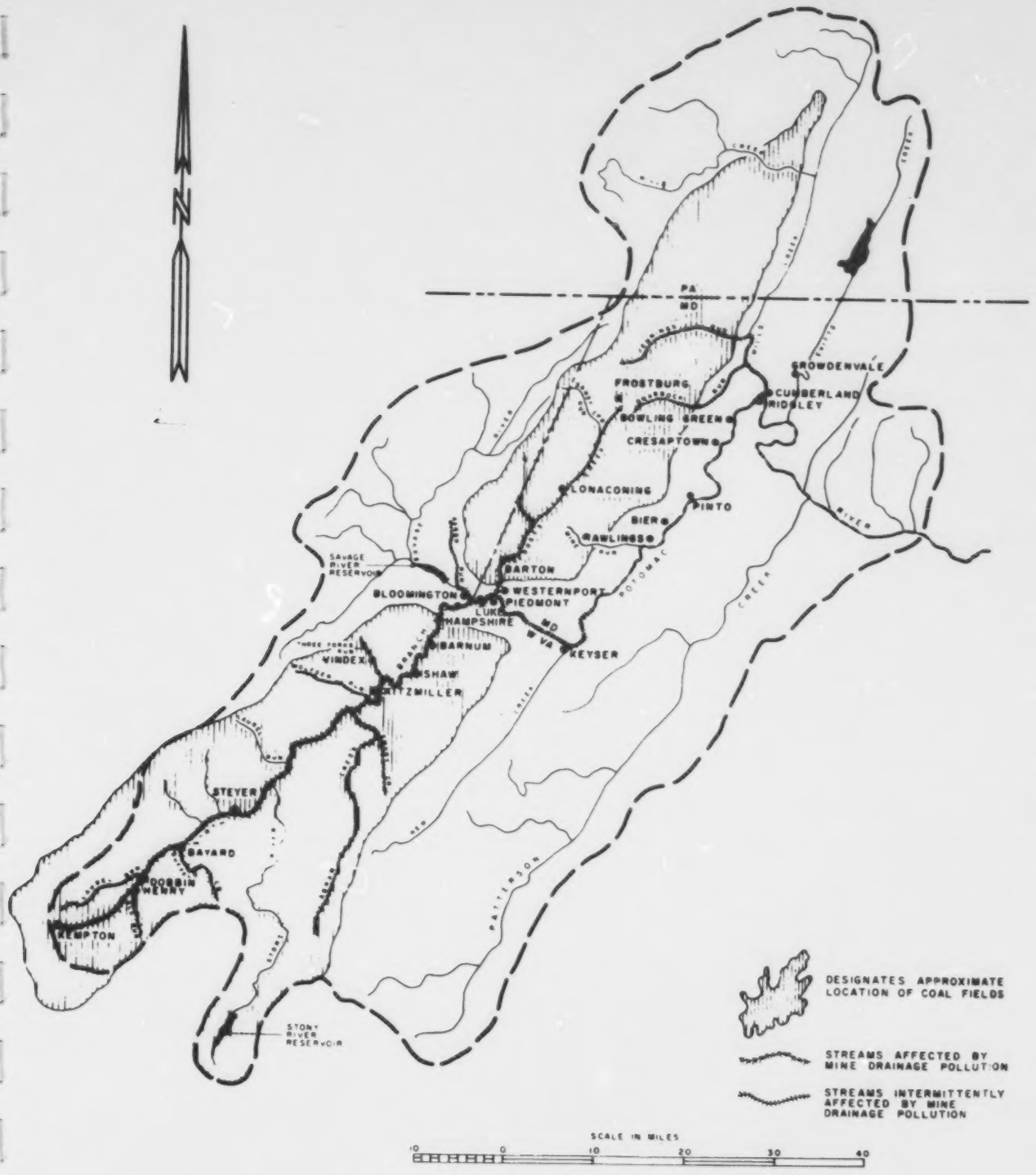
CHAPTER I

INTRODUCTION

A. PURPOSE AND SCOPE

The Chesapeake Technical Support Laboratory (CTSL), Middle Atlantic Region of the Federal Water Pollution Control Administration, as part of the President's Water Quality Task Force on Project Potomac, completed a water quality survey in 1966. The Maryland Department of Water Resources and the West Virginia Department of Natural Resources, Division of Water Resources, cooperated with CTSL in conducting an intensive sampling program in the North Branch Potomac River basin between March 1968 and May 1969. The principal objectives of this study were to:

1. Determine the extent and magnitude of existing mine drainage pollution,
2. Identify streams contributing significant acidic loadings to the North Branch and define temporal distribution and relative magnitudes of acidity,
3. Determine the effects of tributary flows on the main stem of the Potomac River,
4. Define existing stream use limitations resulting from mine drainage pollution,
5. Predict the water quality in the proposed Bloomington Reservoir after impoundment, and the impact of flow releases on downstream water quality during low flow periods,



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6. Suggest the extent of water quality control required to achieve established water quality standards, and

7. Determine design criteria and costs to provide required control measures for each drainage sub-basin.

This study is limited to that portion of the North Branch Potomac River basin currently affected by mine drainage discharges. Geographically, this area includes all the Potomac drainage upstream from Cumberland, Maryland. A basin map is shown as Figure I-1. Basin schematics are shown in Appendix A as Figures A-2 through A-5.

B. AUTHORITY

This report was prepared under the provision of the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et seq.), which directed the Secretary of the Interior to develop programs for eliminating pollution of interstate waters and improving the condition of surface and underground waters.

C. ACKNOWLEDGMENTS

The cooperation of the following governmental agencies, industries and other organizations has enabled CTSL to complete this study and their assistance is gratefully acknowledged:

1. Maryland Department of Water Resources
2. West Virginia Department of Natural Resources, Division of Water Resources
3. U. S. Army Corps of Engineers, Baltimore District

4. West Virginia Pulp and Paper Company*, Luke, Maryland

5. U. S. Geological Survey, Water Resources Divisions at Cumberland, Maryland and Charleston, West Virginia

6. Celanese Fibers Company, Division of Celanese Corporation, Cumberland, Maryland

7. Interstate Commission on the Potomac River Basin

* Recently changed to Westvaco

CHAPTER II

SUMMARY AND CONCLUSIONS

1. For over a century, mine drainage has been the primary cause of degradation in the North Branch Potomac River basin. More than 40 miles of the main stem above Luke, Maryland, and over 100 miles of tributary streams are now virtually devoid of aquatic life because of the effects of mine drainage.
2. The principal constituents of mine drainage in the North Branch Potomac River basin are classified as follows:
    a. Total dissolved and suspended solids,
    b. Acid,
    c. Iron and manganese, and
    d. Toxic precipitates.

    Each of these substances is currently having a deleterious effect on municipal and industrial water supply, fish and aquatic life, water oriented recreation and other prescribed beneficial water uses.
3. The North Branch Potomac River, between Steyer, Maryland and Beryl, West Virginia, contravenes Maryland interstate water quality standards throughout the year. Moreover, many of the tributary streams either continuously or intermittently contravene their respective intrastate standards. The maximum acid concentration and minimum pH value observed in the main stem of the North Branch Potomac were 593 mg/l and 2.3, respectively. Both occurred at the Steyer station.

4. Long-term water quality data, monitored by the West Virginia Pulp and Paper Company, indicate that in recent years a significant deterioration in water quality has occurred. This decrease can be attributed to a combination of low flow conditions and increased mining activities.

5. The tributary streams in the Potomac basin producing most of the acid are:

Elk Run	35,000 lbs/day
Laurel Run	13,000 lbs/day
Buffalo Creek	15,000 lbs/day
Abram Creek	8,000 lbs/day
Stony River	4,500 lbs/day
Three Forks Run	3,300 lbs/day
Piney Swamp Run	3,200 lbs/day
Lostland Run	1,000 lbs/day

6. Approximately 54 percent of the acid loading of the North Branch at Beryl, West Virginia (drainage area of 287 square miles) originates in 20 square miles of tributary streams consisting of Elk Run, Laurel Run, and Buffalo Creek watersheds.

7. An estimated 79,000 lbs/day of acidity is contributed by streams within the State of West Virginia and 39,000 lbs/day by streams within the State of Maryland. These estimates represent 67 percent and 33 percent, respectively, of the total acid loading in the North Branch Potomac River at Beryl.

8. Elk Run, the most seriously degraded tributary stream in the North Branch basin contained acid concentrations approaching 9,000 mg/l and pH values under 2.0.
9. Active coal mines in West Virginia appear to be a significant, and perhaps the largest, source of acid mine drainage while in Maryland, drainage from inactive mines appears to be the most significant source.
10. Since there are no large natural alkalinity sources in the North Branch above the Savage River, an extensive mine drainage control program to eliminate practically all acid discharges is required to achieve water quality standards.
11. The proposed Bloomington Reservoir will impound mine drainage water with acid concentrations ranging from 30 mg/l to 180 mg/l and pH values ranging from 2.7 to 4.9. The annual cost of neutralizing flow releases from the reservoir to comply with Maryland's current pH standard has been estimated at $238,000.
12. A preliminary estimate of annual expenditures required to provide necessary prevention, collection, and treatment measures in the seven most critical watersheds of the Potomac basin is $5,000,000. Capital costs are estimated at $32,500,000.

13. Recent survey data (August 1969) indicate that a "flushing" of mine drainage occurs during high flow periods with resultant acid effects, including a major fish kill, observed in the North Branch Potomac downstream from Cumberland, Maryland.

14. An analysis of the flow release management procedures of the proposed Bloomington Reservoir is essential to minimize the effects of mine drainage in the releases.

CHAPTER III

DESCRIPTION OF THE STUDY AREA

A. HISTORY

The lower Potomac River basin was settled early by English colonists who recognized the potential in development of the upper river as a gateway to the west by means of a canal connecting the Chesapeake Bay to the Ohio River basin. George Washington surveyed the upper river, the Chesapeake and Ohio Canal construction started, and rapid growth in the basin seemed assured.

The advent of the railroad doomed the future of the canal before completion; but the discovery of coal in the North Branch basin, aided by railroad transportion, led to rapid exploitation of this resource in the middle of the nineteenth century. The ravages of the coal mining activity are still evident though mining continues under regulations to conserve the other natural rescurces: water, forests, and landscapes.

B. GEOGRAPHY

The North Branch of the Potomac River rises in Tucker County, West Virginia near the Fairfax Stone marking the historic western boundary of Maryland with Virginia, now West Virginia, and flows alternately northeast and southeast for about 98 miles to join the South Branch near Oldtown, Maryland to form the Potomac River. Two miles downstream from its source, below Kempton, Maryland, the right bank forms the southern boundary between Maryland and West Virginia.

On the Maryland side the river is bounded by Garrett and Allegany counties and on the West Virginia side by Grant, Mineral, and Hampshire counties.

The basin's coal-bearing area lies mainly in this trough-shaped valley, about 80 miles long with its axis in a northeast-southwest direction. The North Branch flows northeastward along this axis for almost 50 miles, then bends to the southeast at the three industrial communities of Luke, Westernport, and Piedmont, and there leaves the coal-bearing area. Above Luke it is known as the upper Potomac coal field. The northeastern valley is drained by Georges Creek which flows southwestward to join the North Branch at Westernport.

Both the North Branch and Georges Creek valleys are steep, narrow, and heavily wooded. Most of the tributaries are short hillside runs with less than ten square miles of drainage area discharging directly into the main stem. The exceptions are Stony River and Abram Creek which drain much of the North Branch basin above Luke on the West Virginia side. These tributaries, both of which lie in the coal-bearing region, each approach 50 square miles in drainage area at their mouth. The study area encompasses some 875 square miles and is shown in Figure I-1.

C. HYDROLOGY

The flow in Stony River is regulated by West Virginia Pulp and Paper Company's Reservoir about 19 miles upstream from the North Branch and to a minor extent by a Virginia Electric and Power Company

dam about nine miles upstream from the North Branch. A reservoir near the U. S. Route 50 crossing at Mount Storm, West Virginia has been proposed by the Corps of Engineers.

Savage River, which lies for the most part outside the coal region, joins the North Branch just upstream from Luke. Its flow is regulated by the Corps of Engineers' Savage River Reservoir about five miles upstream from the North Branch. A reservoir upstream from the existing reservoir (Savage II) has been proposed by the Corps of Engineers. The Corps of Engineers has also proposed a large reservoir, the Bloomington Project, on the North Branch approximately eight miles upstream from Luke.

Because of the steep and generally impervious terrain, streams in this region respond rapidly to changes in rain or snow runoff and tend to have low dry-weather flows. Pertinent data for gaging stations within the study area can be found in Table III-1.

D. GEOLOGY

The predominant coal-bearing geological formations in the upper Potomac coal basin are the Conemaugh, Allegheny, and Pottsville formations of the Pennsylvania system in order of depth from the surface as well as increasing resource value. The first two outcrop in the basin, but all have been reached and worked from mine shafts. In the Georges Creek coal basin the Monongahela formation with its thick Pittsburgh coal seam was formerly the most productive source but has gradually become exhausted and was the major cause of

decline in mining activity in this area. Modern mining methods have made it feasible to recover coal from previously uneconomical seams with the promise of coal mining activity in the area for a long time.

Coal was discovered in the Georges Creek basin in 1782 and has been mined in the North Branch basin for about 150 years. A mine was operating before 1816 at Eckhart, Maryland in Georges Creek field, and output increased rapidly until the early twentieth century.

Maryland's peak production, 5.5 million tons of coal, occurred in 1907, earlier than any other coal-producing state. Coal production in the North Branch basin for the 1961-1965 period was:

1961 . . . . . 1.0 million tons

1962 . . . . . 1.0 million tons

1963 . . . . . 1.3 million tons

1964 . . . . . 2.2 million tons

1965 . . . . . 3.3 million tons

The 1965 North Branch production amounted to 0.65 percent of national production. About 2.2 million tons were mined in West Virginia (upper Potomac field) and 1.1 million tons in Maryland. Of the 1965 Maryland production, 624,000 tons were mined from the upper Potomac field. The upper Potomac field accounted for 85 percent of the 1965 North Branch basin coal production, and the West Virginia part of the upper Potomac field made up the bulk of the recent increases. While production for the entire North Branch basin increased 330 percent from 1961 to 1965,

Maryland production increased only 60 percent. These increases were probably a result of use of modern mining methods and increased demand for electric power generation.

The many coal seams are interspersed with marine shales, clays, and sandstones. Calcareous rocks, unfortunately, are not characteristic of the basin and are sparsely present in thin strata. Such alkaline rocks could have provided neutralization potential for the acids found in mine drainage discharges. Where limestone does occur in the Savage River basin, it is believed to have provided the alkalinity in Savage Reservoir and consequently some neutralization of acidity in the North Branch at Westernport.

E. ECONOMY

Cumberland, Maryland, the largest population center in the North Branch basin, is the railroad and industrial center of the area. It has been a transportation center since the early 1800's when the National Road, now U. S. 40, was built.

In 1842 the Baltimore and Ohio Railroad, and in 1850 the Chesapeake and Ohio Canal, reached Cumberland and rapid growth in coal mining began. Today the area is also served by the Western Maryland and Pennsylvania Railroads. In addition to the railroad activity, three large industrial plants with employment ranging from 1,100 to 3,100 are located in the Cumberland area.

The remainder of the basin is sparsely populated. Principal towns are Frostburg, Barton, Lonaconing, Oakland, and Luke-Westernport

in Maryland and Piedmont and Keyser in West Virginia. The West Virginia Pulp and Paper Company mill located in the tri-town area of Luke-Westernport-Piedmont employs 2,400 persons and is the largest "fine paper" mill in the world.

Coal output per man increased three times as fast in Maryland during 1961-1965 as in the adjacent states; and in 1965, the output per man was far greater in the Maryland upper Potomac basin than in the Georges Creek basin. This was a result of new explorations and investment in new equipment and was also experienced in the West Virginia upper Potomac basin.

Because of the increased output per man, mining employment in the North Branch basin did not increase in proportion to production during 1961-1965. Employment for these years was:

1961 617

1963 657

1963 631

1964 784

1965 851

In 1965, 373 men were employed in Maryland and 478 in West Virginia. This includes not only miners but all mine-associated employees.

The average value of Maryland coal in 1965 was $3.63 per ton f.o.b. mine, below the average U. S. price of $4.44 and the Pennsylvania (including anthracite) and West Virginia values of $5.07 and $4.87, respectively. Coal values have been stable since 1950, the average fluctuating within a range of 69 cents per ton from 1950 to

1965 with West Virginia upper Potomac basin values probably comparable. This would make the total 1965 North Branch basin coal production worth about $12 million, or 0.53 percent of the value of all coal mined in the United States in 1965. Of this the West Virginia upper Potomac coal field production during 1965 would have been $8 million, about one percent of the total value of the West Virginia coal production. The Maryland 1965 production of $4 million was an almost insignificant three ten-thousandths of one percent of the gross Maryland state product, but about five percent of the total value of the mineral industry in Maryland.

TABLE III-1

STREAMFLOW OF NORTH BRANCH POTOMAC RIVER AND TRIBUTARIES ABOVE CUMBERLAND, MARYLAND

USGS Gaging Station	Drainage Area (sq.mi.)	Streamflow Mean (cfs)	Median (cfs)	7 Day* 10 yr. Flow (cfs)	Remarks
North Branch at Steyer, Md.	73.0	160	89	4.6	Median and 7d-10 yr. flows estimated from relation with Kitzmiller gage.
Stony River at Mt. Storm, W. Va.	48.8	82.1	-	-	Below dam, records unadjusted.
Abram Creek at Oakmont, W. Va.	47.3	61.5	27.7	-	Median from USGS provisional records, subject to revision.
North Branch at Kitzmiller, Md.	225	424	238	14	Adjusted for storage in Stony River Reservoir.
North Branch at Bloomington, Md.	287	498	284	20	Beryl, W. Va. discontinued 1950.
Savage River at Bloomington, Md.	106	162	76	1.8	Below Savage River dam records adjusted for storage.
North Branch at Luke, Md.	404	681	356	48	Records adjusted for storage in Stony and Savage River Reservoirs.
Georges Creek at Franklin, Md.	72.4	77.9	36	2.7	
North Branch at Pinto, Md.	596	859	458	54	Unadjusted.

* Design flow prescribed by Maryland's and West Virginia's water quality standards. 7 consecutive day low flow with a 10 year return frequency.

CHAPTER IV

FRAMEWORK FOR ANALYSIS

A. MINE DRAINAGE CHEMISTRY

Sulfur and iron compounds found with coal deposits become exposed to air and water during mining operations and produce dissolved iron salts and sulfuric acid that interact to form iron, aluminum, calcium and magnesium sulfates some of which form toxic precipitates. In addition manganese, sodium, potassium, and other elements may be present in the resulting drainage as chlorides, carbonates, and sulfates.

Mine drainage control methods are based upon preventing the exposure of pyrite or iron disulfide to air and water in order to reduce formation of sulfuric acid and other undesirable constituents.

Although investigators differ concerning the specific reactions and mechanisms involved in the formation of mine drainage, the overall reactions can be represented by the following equations:

$$2\,FeS_2 + 7O_2 + 2H_2O \rightarrow 2\,FeSO_4 + 2H_2SO_4$$

(pyrite) (oxygen) (water) (ferrous sulfate) (sulfuric acid)

$$FeS_2 + 3O_2 \rightarrow FeSO_4 + SO_2$$

(sulfur dioxide)

$$2\,SO_2 + O_2 + 2H_2 \rightarrow 2H_2SO_4$$

The reaction yields two moles of hydrogen ions, H+, (acidity) for each mole of iron oxidized.

Initially, the iron in mine drainage is in the ferrous state; however, after contact with air, ferrous iron oxidizes to ferric iron according to the following equation:

$$4\ FeSO_4 + 2H_2SO_4 + O_2 \rightleftharpoons 2\ Fe_2(SO_4)_3 + 2H_2O$$

(ferric sulfate)

While the oxidation of pyrite produces sulfuric acid, the above equation indicates that the additional oxidation of iron utilizes sulfuric acid. Dependent upon pH, temperature, and concentration of constituents the reaction proceeds:

$$Fe_2(SO_4)_3 + 6H_2O \rightleftharpoons 2\ Fe(OH)(SO_4) + SO_4$$

(ferric sulfate) (water) (basic ferric sulfate) (sulfate ion)

In the absence of acid, basic ferric sulfate may precipitate directly according to the following reaction:

$$4\ FeSO_4 + O_2 + 2H_2O \rightleftharpoons 4\ Fe(OH)(SO_4)$$

(commonly referred to as "yellow-boy")

There is some question as to whether the basic ferric sulfate is a discrete compound or a ferric hydroxide containing occluded sulfate.

In the presence of strong acid concentrations, ferrous sulfate may hydrolyze as follows:

$$FeSO_4 + 2H_2O \rightleftharpoons Fe(OH)_2 + H_2SO_4$$

The above equations which describe the formation of mine drainage compounds are theoretical. As such, they may not always define

what occurs in the field since mine drainage involves a highly dynamic and complex system, encompassing both chemical and biological reactions.

B. WATER QUALITY STANDARDS AND IMPLEMENTATION PLANS

1. State of Maryland

a. Water Use and Water Quality Criteria

The State of Maryland has adopted water quality standards for all surface waters within the State. Standards pertaining to interstate streams were approved by the U. S. Department of the Interior on August 7, 1967. The principal indicator prescribed by Maryland's standards for waters receiving mine drainage pollution is pH. The water uses to be protected and the corresponding pH criteria for that portion of the North Branch Potomac basin upstream from the City of Cumberland can be found in Table IV-1.

The water quality standards established by the State of Maryland are to apply at all times when flows are equal to or greater than the minimum seven-consecutive-day-low-flow with a ten-year return frequency.

b. Implementation Plan

The State of Maryland has proposed the following programs in an effort to abate the pollution resulting from mine drainage:

(1) The Maryland Bureau of Mines and the Maryland Department of Water Resources will conduct frequent inspections of active operations to determine if standards are being met. If they are not being met, additional improvement and early action to correct offending conditons will be required.

(2) A regulation on mine drainage control will be prepared subsequent to conferences with the Land Reclamation Advisory Committee*. Such a regulation will only require corrective measures which are economically feasible and practicable of attainment and may not correct all mine drainage pollution especially that caused by abandoned deep mines.

(3) When methods of controlling or minimizing mine drainage from abandoned mines are developed by existing experimental work, the State will initiate a program for such corrective action.

2. State of West Virginia

a. Water Uses and Water Quality Criteria

The interstate and intrastate stream standards adopted by the State of West Virginia were approved by the U. S. Department of the Interior in May, 1968. Water uses to be protected for the State of West Virginia can also be found in Table IV-1.

Standards which apply to a two mile reach of the Potomac, below its source and all tributary streams within West Virginia containing acid mine drainage, prescribe the following criteria:

(1) Less than 30.0 mg/l aluminum,

(2) Less than 10.0 mg/l total iron,

(3) pH greater than 5.5,

(4) Less than 200 mg/l total suspended solids, and

(5) Less than 200 mg/l sulfates.

* As of July 1, 1969, know as Land Reclamation Committee

TABLE IV - 1

WATER USES NORTH BRANCH POTOMAC RIVER BASIN

	Water	Zone	Water Uses to be Protected	pH Criteria
1.	N. Br. Potomac R. (interstate) Maryland	From W. Va. - Md. State Line to W. Va. Pulp & Paper Water Supply Dam in Luke, Md.	Municipal Water Supply Agricultural Water Supply Industrial Water Supply Fish & Aquatic Life (trout) Water Contact Recreation	6.0 - 8.5
2.	N. Br. Potomac R. (interstate) Maryland	W. Va. Pulp & Paper Water Supply Dam in Luke, Md. to Dam at Cumberland, Md.	Agricultural Water Supply Industrial Water Supply	5.0 - 9.0
3.	Savage River (intrastate) Maryland	Headwaters to mouth	Same as Number 1	6.0 - 8.5
4.	Georges Creek (intrastate) Maryland	Headwaters to mouth	Fish & Aquatic Life	6.0 - 8.5
5.	All other tribs. to N. Br. Potomac in Garrett & Allegany Counties (intrastate) Maryland	Headwaters to mouth	Water Contact Recreation Fish & Aquatic Life (trout) Agricultural Water Supply	6.0 - 8.5
6.	All waters and tribs. of the N. Branch, W. Va.	All waters except those covered by Section 5.03 (a)	Water Contact Recreation Water Supply, Public, Industrial, & Agricultural Propagation of Fish and Aquatic Life	6.0 - 8.5

b. Implementation Plan

In an effort to determine the feasibility and costs of methods devised to control acid mine drainage from abandoned mines, the Federal Government in cooperation with the State of West Virginia has undertaken a mine drainage control project on Roaring Creek in Randolph County. Information obtained from this project, and other similar projects throughout the country, will ultimately be applied to the entire abandoned mine drainage problem affecting interstate and intrastate streams within West Virginia.

The State of West Virginia feels that the coal industry's progress toward stream pollution control from active mines has been too slow and therefore plans to initiate a program which will accelerate this progress. A program to prevent the possibility of future pollution from active mines is already in effect. Before a coal company is issued a permit to discharge water into a stream, there must be complete assurance that this water will not pollute the stream. Pollution is defined as a contravention of stream standards.

C. WATER QUALITY SURVEILLANCE PROGRAMS

1. State Surveys

The Maryland Department of Water Resources conducts a continuing surveillance program to monitor the water quality in streams affected by mine drainage. MDWR has also compiled extensive information regarding the locations of individual mines, the area currently disturbed by strip mining, and effluent analysis for each of the mines

contributing drainage. In addition, MDWR has conducted a pH survey of all Maryland streams and many West Virginia tributaries to the North Branch.

A routine surveillance program is currently being maintained by the West Virginia Department of Natural Resources, Division of Water Resources.

2. Water Quality Monitoring by Industries

In the reach from Luke, Maryland to Cumberland, Maryland, ten water quality surveillance stations are currently being maintained by three industries. Of the ten stations, five are maintained by the West Virginia Pulp and Paper Company; two by the Celanese Fibers Company; and three by the Kelly-Springfield Company.

Data from the surveillance network is summarized annually by the Interstate Commission on the Potomac River Basin.

3. FWPCA Cooperative Surveys

The Chesapeake Technical Support Laboratory of FWPCA conducted mine drainage surveillance programs in the North Branch Potomac River, upstream from Cumberland, Maryland, during August and October of 1966 and April and November of 1967.

In March 1968, a bi-weekly sampling program was initiated in cooperation with the Maryland Department of Water Resources and the West Virginia Department of Natural Resources, Division of Water Resources. This program was funded in part by the U. S. Army Corps of Engineers, Baltimore District, from their Bloomington Reservoir

Project. For a period of about fourteen months, eighteen stations were maintained by CTSL personnel and four by MDWR and WVDNR personnel.

A description of the sampling stations and all data collected since March 1968, are given in Appendices A and B. Sampling stations are also indicated on the basin map (Figure I-1) and on basin schematic diagrams (Figures A-2 through A-5).

D. ABATEMENT CONSIDERATIONS

To achieve a water quality that will allow the desired uses of the North Branch Potomac River, a reduction of certain undesirable constituents normally found in mine drainage is necessary. The constituents of greatest importance are:

1. Total dissolved solids,
2. Acidity,
3. Iron and manganese, and
4. Toxic precipitates.

Each of the above has a deleterious effect on water usage and will be discussed in a later chapter. The primary problem created by mine drainage, however, is a result of excessive acidity and the corresponding decrease in pH. In order to simulate the response of pH to a reduction in acidity (or increase in net-alkalinity) attributable to an abatement effort, a net alkalinity versus pH relationship was established for the North Branch Potomac River from existing stream sampling data (Figure IV-1). A plot of this type serves as a

"tool" for ascertaining the amount of acidity removal; i.e., degree of abatement required to increase pH to the minimum levels specified by the approved state stream standards. Moreover, it is particularly useful for determining the quantity of acid which must be neutralized to upgrade flow releases from the proposed Bloomington Reservoir to acceptable levels. Chapter VII (C) of this report discusses the requirements pertaining to the Bloomington Reservoir. The general mine drainage pollution abatement program is discussed in Chapter VIII.

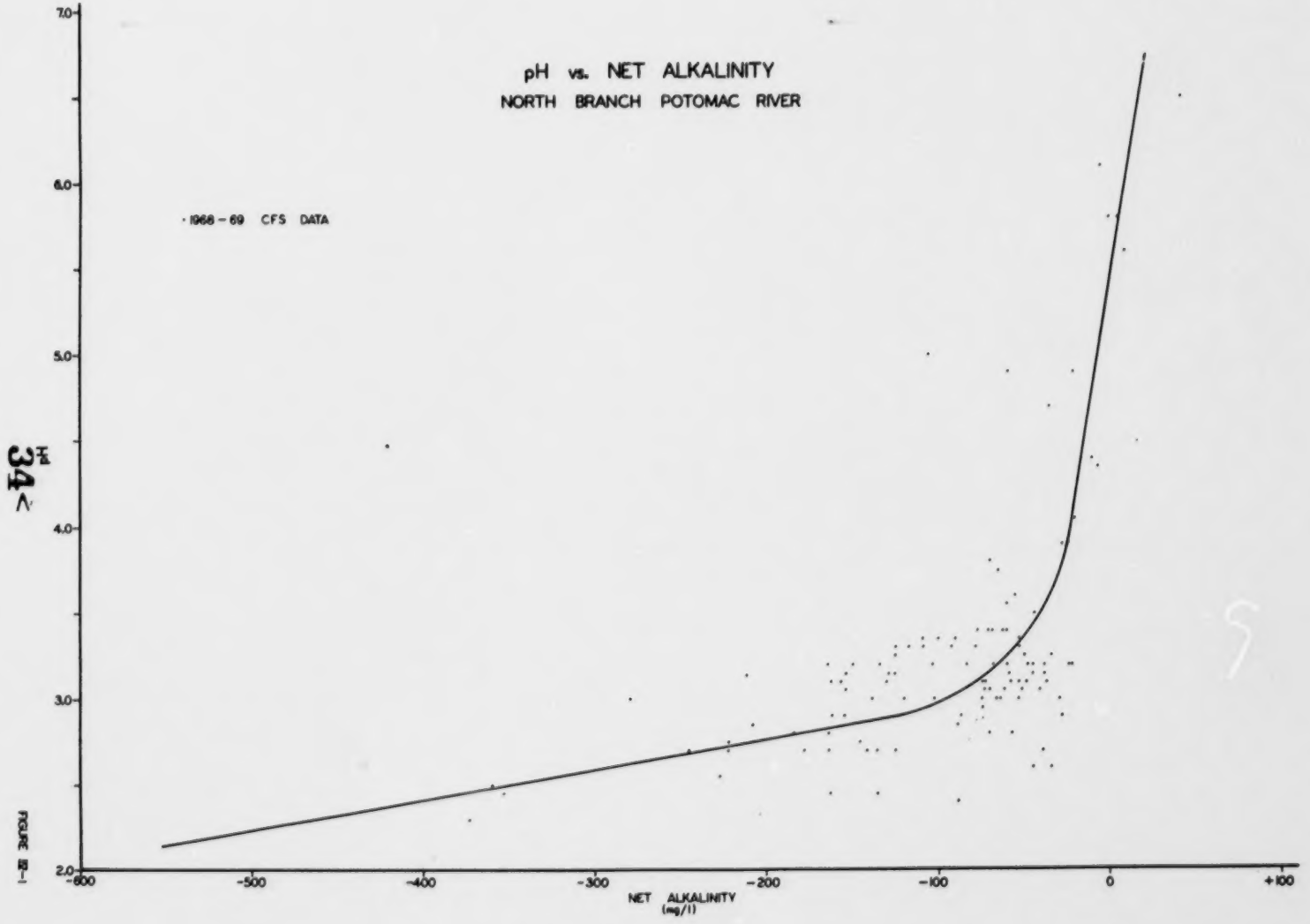

pH vs. NET ALKALINITY
NORTH BRANCH POTOMAC RIVER
· 1968 – 69 CFS DATA
pH
7.0
6.0
5.0
4.0
3.0
2.0
-600
-500
-400
-300
-200
-100
0
+100
NET ALKALINITY
(mg/l)

FIGURE B-1

CHAPTER V

WATER QUALITY CONDITIONS

For ease of data presentation, the water quality conditions in the North Branch are described in four separate geographical areas as listed below:

Area Notation	Area
A	Headwaters to Steyer, Md.
B	Steyer, Md. to Kitzmiller, Md.
C	Kitzmiller, Md. to Beryl, W. Va.
D	Beryl, W. Va. to Keyser, W. Va.

Data plots of pH, net alkalinity or acidity, and stream discharge are exhibited for each surveillance station.

A. HEADWATERS TO STEYER, MARYLAND

The water quality in this area was monitored at four sampling stations, three of which were on tributary streams and one on the main stem of the North Branch. The three tributaries sampled were Elk Run, Laurel Run, and Buffalo Creek.

1. Elk Run (West Virginia)

As presented in Figure V-1, acidity concentrations in Elk Run approached 9,000 mg/l during low flow periods. Pronounced decreases in acidity occurred during high flow periods but concentrations still ranged in the vicinity of 2,000 - 3,000 mg/l. From the standpoint of acidity, Elk Run is by far the most critical stream in the entire North Branch Potomac basin.

ELK RUN

HENRY SIDING, W. Va.

SURVEY DATA

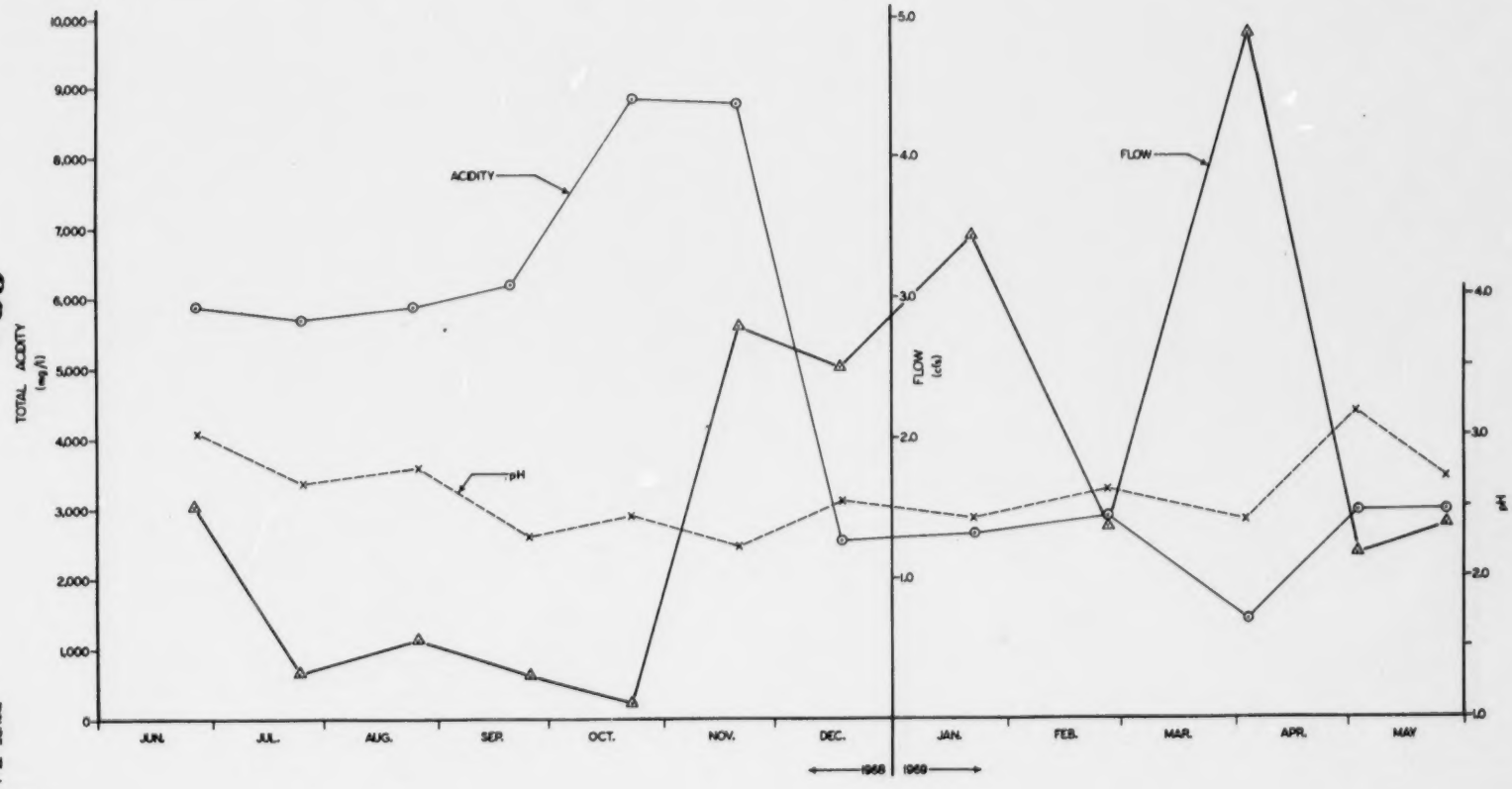


FIGURE IX-1

The high amount of acidity in Elk Run has produced exceedingly low pH values. In almost every instance pH was less than 3.0 and in some cases it was under 2.0. The pH values shown in Figure V-1 indicate a relatively small amount of annual variation and apparently a lack of dependence upon flow. The pH levels observed in Elk Run were considerably less than the minimum pH (5.5) prescribed by the State of West Virginia for its interstate and intrastate streams containing acid mine drainage.

2. Laurel Run (Maryland)

Limited data presented in Figure V-2 indicate that Laurel Run contains large quantities of mine drainage. Maximum acidity concentrations approached 600 mg/l and pH values were less than 3.0. Acidity appeared to be inversely related to flow while pH was not.

Although Laurel Run does not have acidity concentrations as high as that of Elk Run, nevertheless, the Maryland stream standards (pH 6.0) are contravened.

3. Buffalo Creek (West Virginia)

As in Elk Run, there is a definite relationship between acidity and flow in Buffalo Creek (Figure V-3). Low flow periods produced acidity concentrations exceeding 600 mg/l whereas high spring flows reduced acidity to approximately 100 mg/l.

The pH also varied somewhat with river discharge as shown in Figure V-3. On an annual basis, pH levels were usually between 2.0 and 3.0. In general the water quality in Buffalo Creek is comparable to that of Laurel Run.

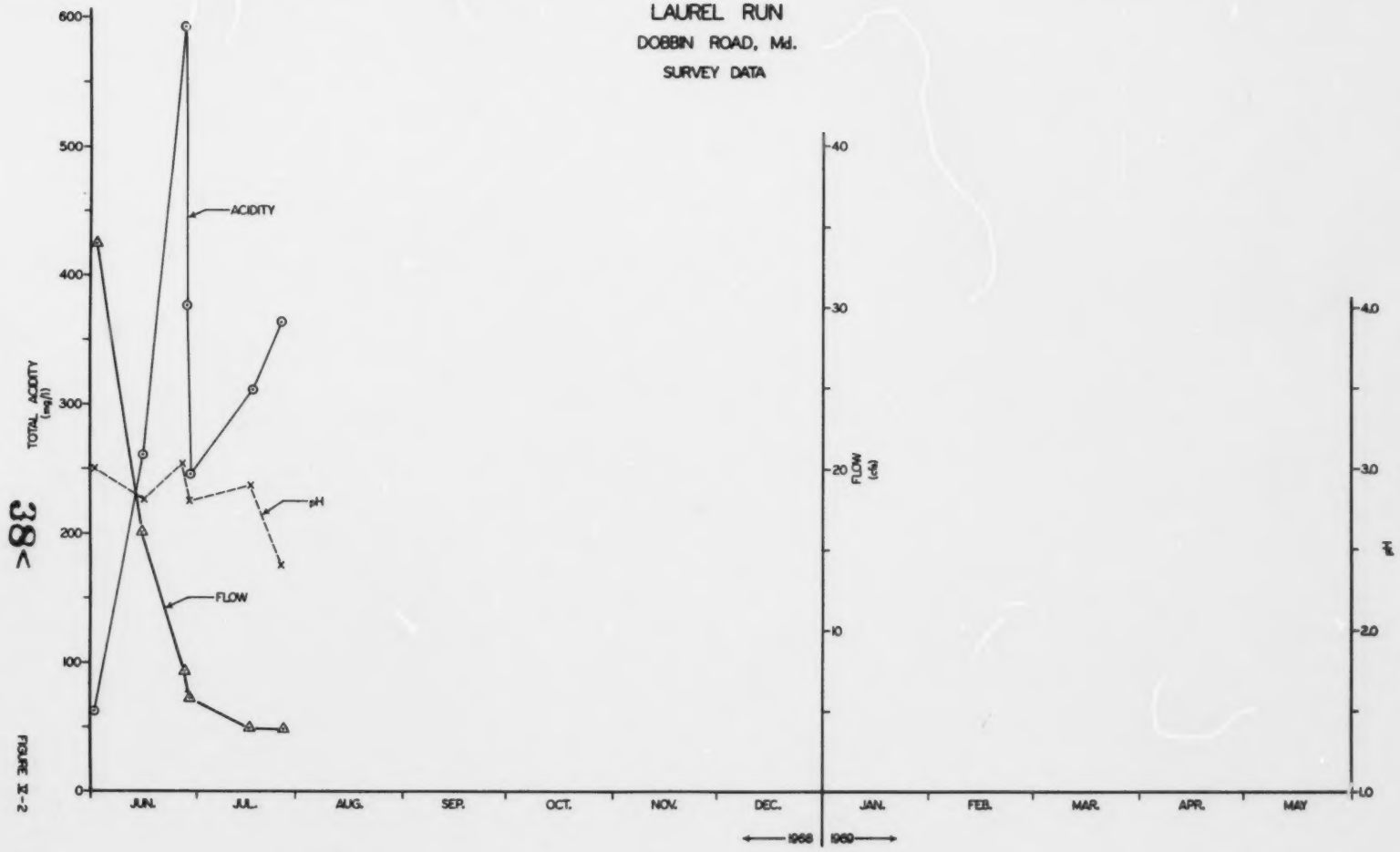

LAUREL RUN
DOBBIN ROAD, Md.
SURVEY DATA
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
ACIDITY
FLOW
600
500
400
300
200
100
0
40
30
20
10
4.0
3.0
2.0
1.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE II-2

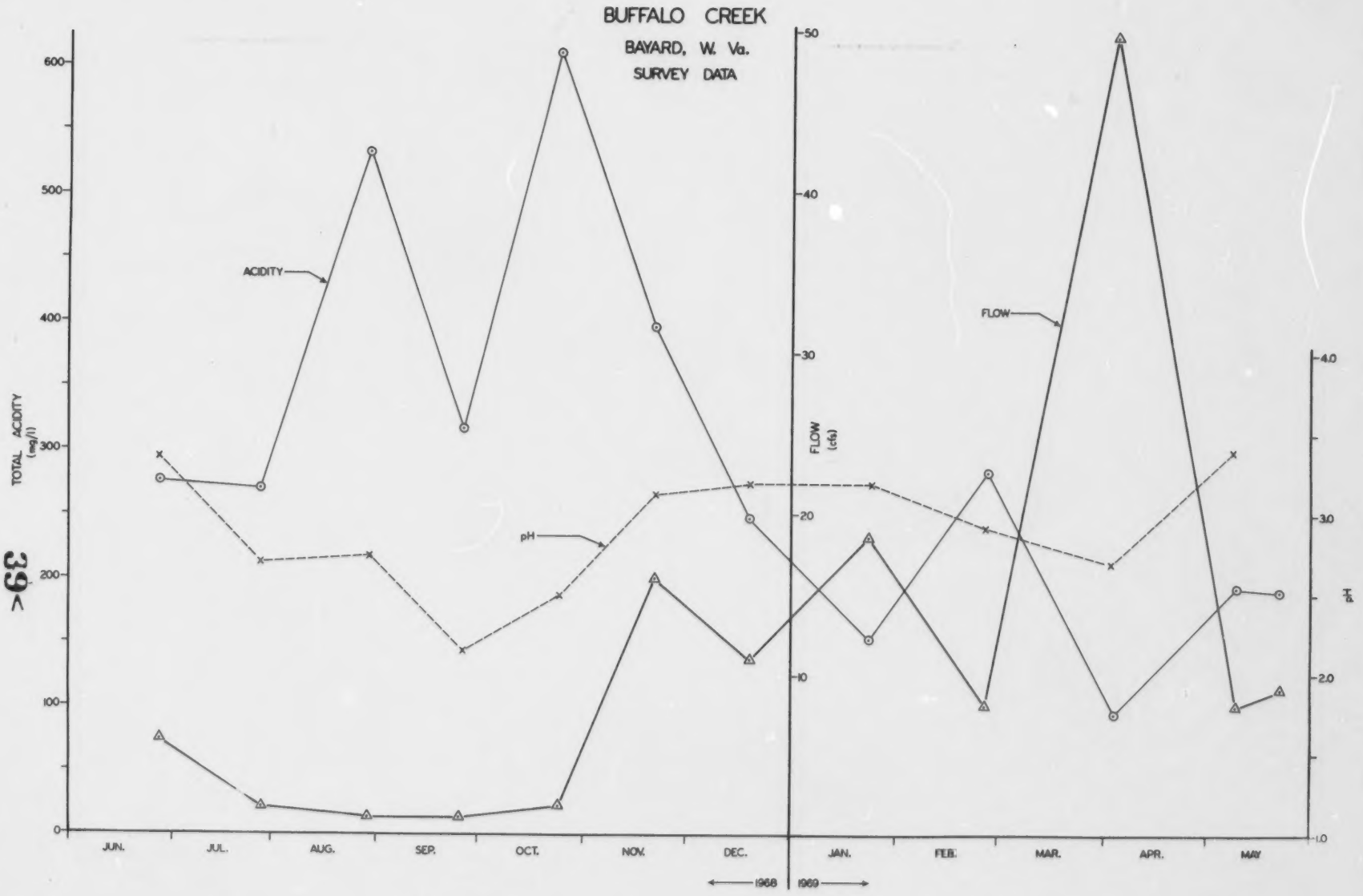

BUFFALO CREEK
BAYARD, W. Va.
SURVEY DATA
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
ACIDITY
FLOW
600
500
400
300
200
100
0
50
40
30
20
10
4.0
3.0
2.0
1.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE IX-3

The pH of the water in Buffalo Creek does not comply with the water quality standards prescribed for this stream by the State of West Virginia.

4. North Branch at Steyer, Maryland

The mine drainage contributed by Elk Run, Laurel Run, and Buffalo Creek is reflected in the water quality of the North Branch at Steyer, Maryland. Figure V-4 shows an erratic acidity relationship with flow. Maximum acid concentrations approaching 600 mg/l were recorded during the critical late summer months. Minimum values observed during the winter and spring were less than 100 mg/l.

The pH values generally ranged from 2.3 to 3.3 and like acidity were somewhat related to flow. The lower pH levels prevailed during low flow periods. Both the acid concentrations and the pH observed at Steyer were the most critical of any station on the North Branch Potomac River.

The Maryland stream standards for North Branch Potomac specify a minimum pH of 6.0. This criterion is not being attained at any time or under any flow condition.

B. STEYER TO KITZMILLER, MARYLAND

In this area water quality was monitored at four sampling stations, three of which were on the Stony River, Lostland Run, and Abram Creek tributaries. The North Branch station was at Kitzmiller.

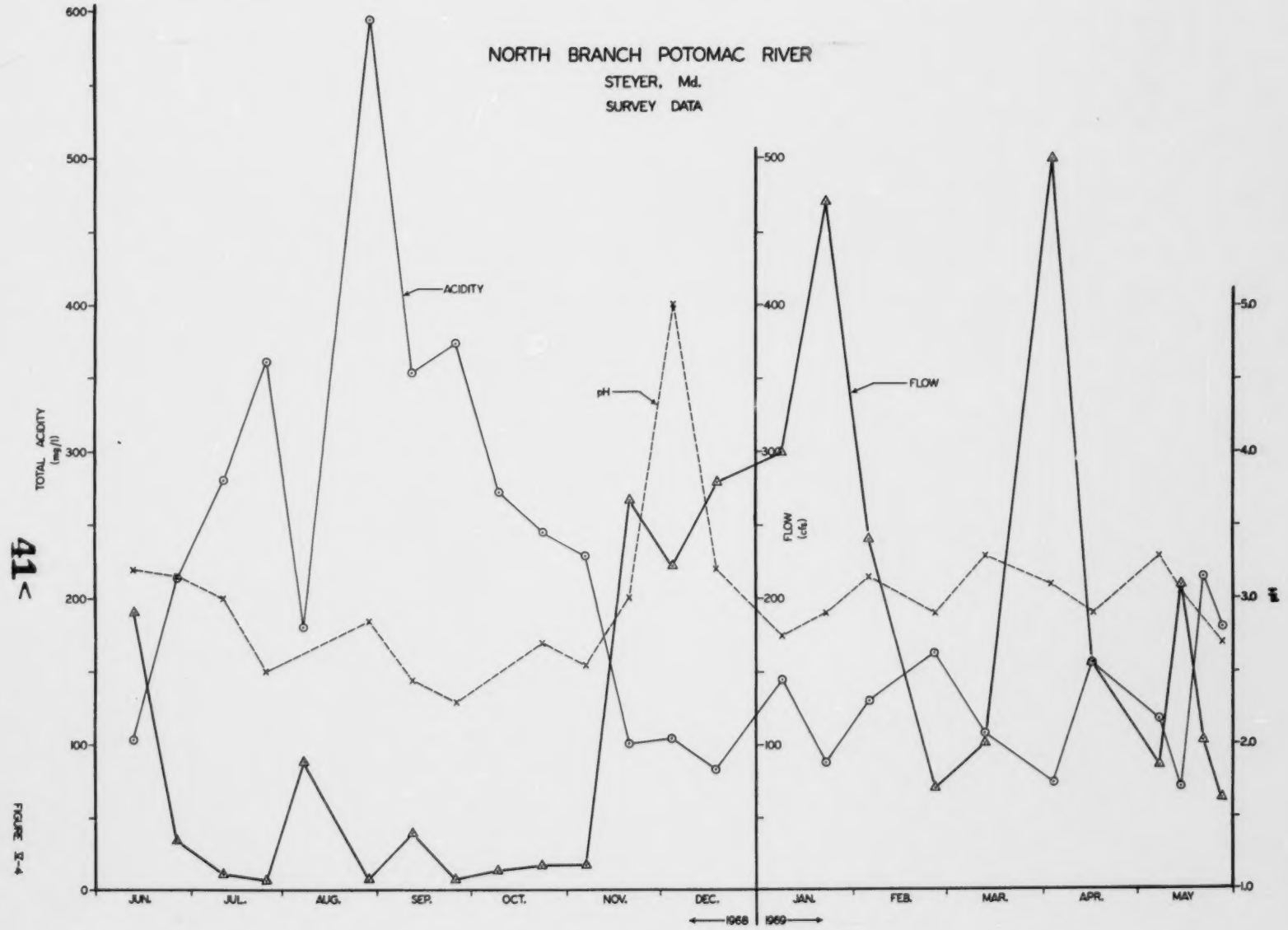

NORTH BRANCH POTOMAC RIVER
STEYER, Md.
SURVEY DATA
ACIDITY
pH
FLOW
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
600
500
400
300
200
100
0
500
400
300
200
100
5.0
4.0
3.0
2.0
1.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE II-4

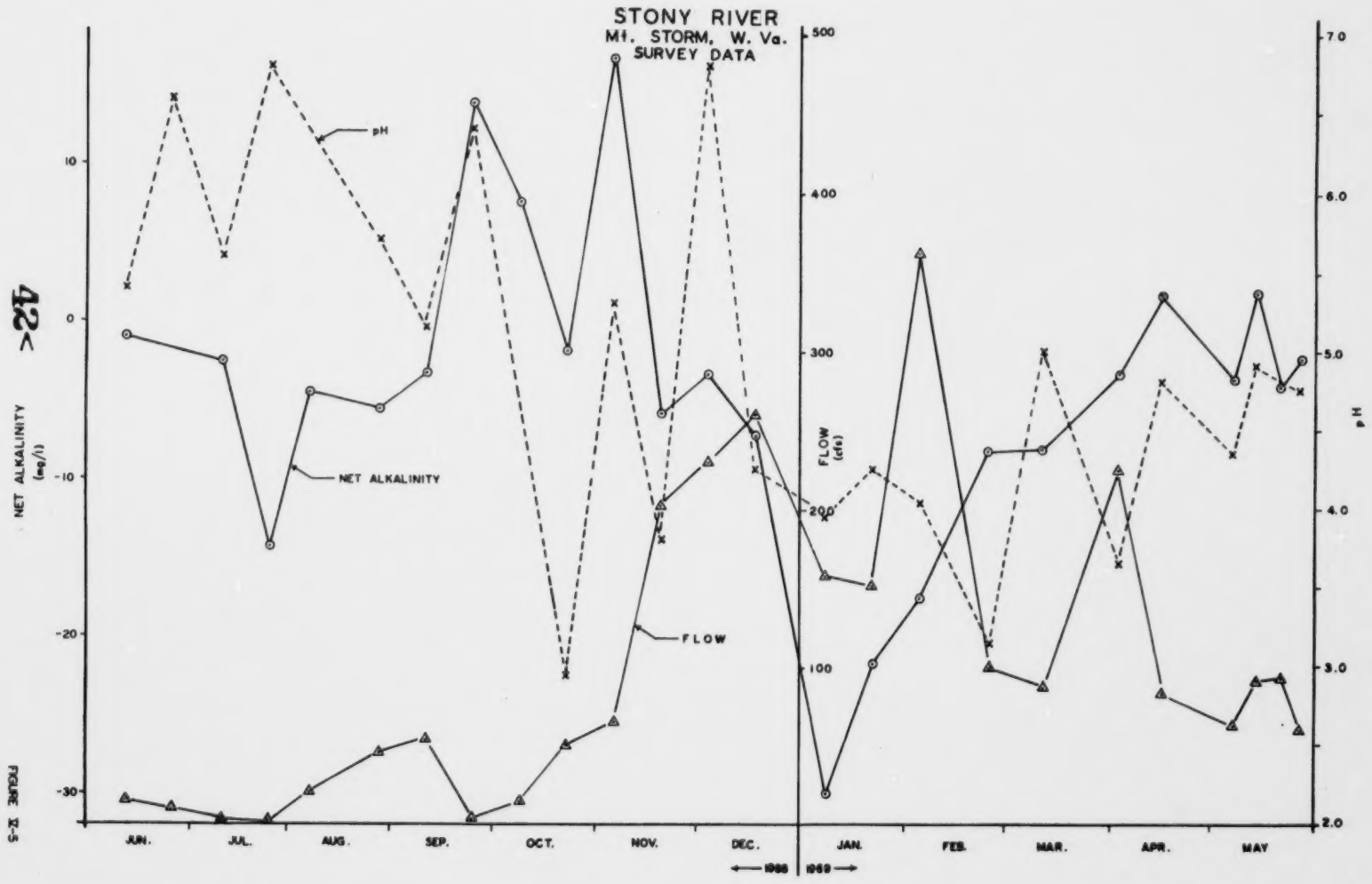


FIGURE 12-5

42 <27

1. Stony River (West Virginia)

During the survey, the net alkalinity* of Stony River varied from -30 mg/l to +16 mg/l but net alkalinity (Figure V-5) was negative during most of the year with only isolated peaks of positive net alkalinity observed. No relationship appears to exist between net alkalinity and flow.

The pH levels in Stony River generally vary in a manner similar to net alkalinity. Values approaching 7.0 (neutrality) occurred during periods of positive net alkalinity while minimum values of 3.0 were observed when net alkalinity indicated acid conditions.

Water quality standards for this reach of the stream containing the drainage from Laurel Run, however, are not being met throughout the year.

2. Lostland Run (Maryland)

An inverse relationship exists between acidity and flow, as shown in Figure V-6. No relationship exists between pH and flow. Maximum acidity concentrations of 130 mg/l occurred during September and October. The spring months showed a decrease in acidity to approximately 15 mg/l.

* The net alkalinity is defined as total alkalinity minus total acidity. It can assume either a positive or negative sign depending on whether the alkalinity (positive) or acidity (negative) is greater.

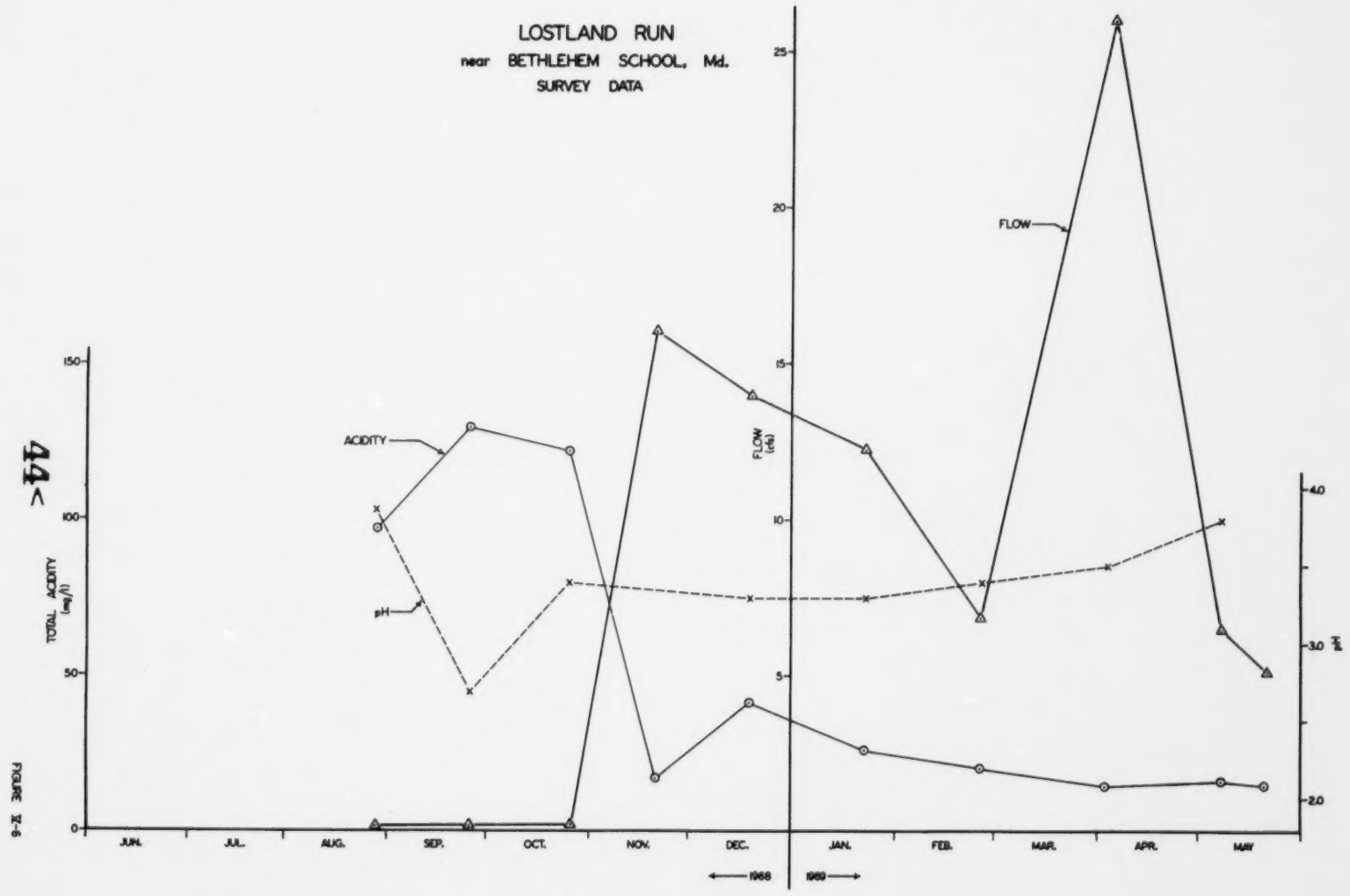

LOSTLAND RUN
near BETHLEHEM SCHOOL, Md.
SURVEY DATA
ACIDITY
pH
FLOW
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
150
100
50
0
25
20
15
10
5
4.0
3.0
2.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE 12-6

The pH levels for Lostland Run varied between 3.0 and 4.0. A minimum pH of 2.7 was observed in September.

The Maryland stream standards for Lostland Run are currently being contravened on a continuous basis.

3. Abram Creek (West Virginia)

The maximum and minimum concentrations of acidity at the sampling station were approximately 180 mg/l and 10 mg/l, respectively. As shown in Figure V-7, the acidity occurred during the late summer and fall while depressed levels were observed in the spring.

The pH was relatively constant, ranging between 3.0 and 4.0. The quality of Abram Creek does not comply with West Virginia's intrastate stream standards.

4. North Branch at Kitzmiller, Maryland

When Figures V-4 and V-8 (North Branch at Steyer) are compared, the similar yearly patterns for acidity, pH, and flow can readily be seen. In certain instances, the peaks at Kitzmiller were observed at a later date than those observed at Steyer which would compensate somewhat for the travel time between the two stations.

In terms of acidity concentration, there appears to be a definite improvement in the water quality at Kitzmiller. The maximum acid concentrations at Kitzmiller were about 220 mg/l whereas comparable values approached 600 mg/l at Steyer.

The reduction in acidity concentration can be attributed to the diluting effects of all tributary streams between Steyer and Kitzmiller. The differences in pH were not as pronounced as those in acidity. The

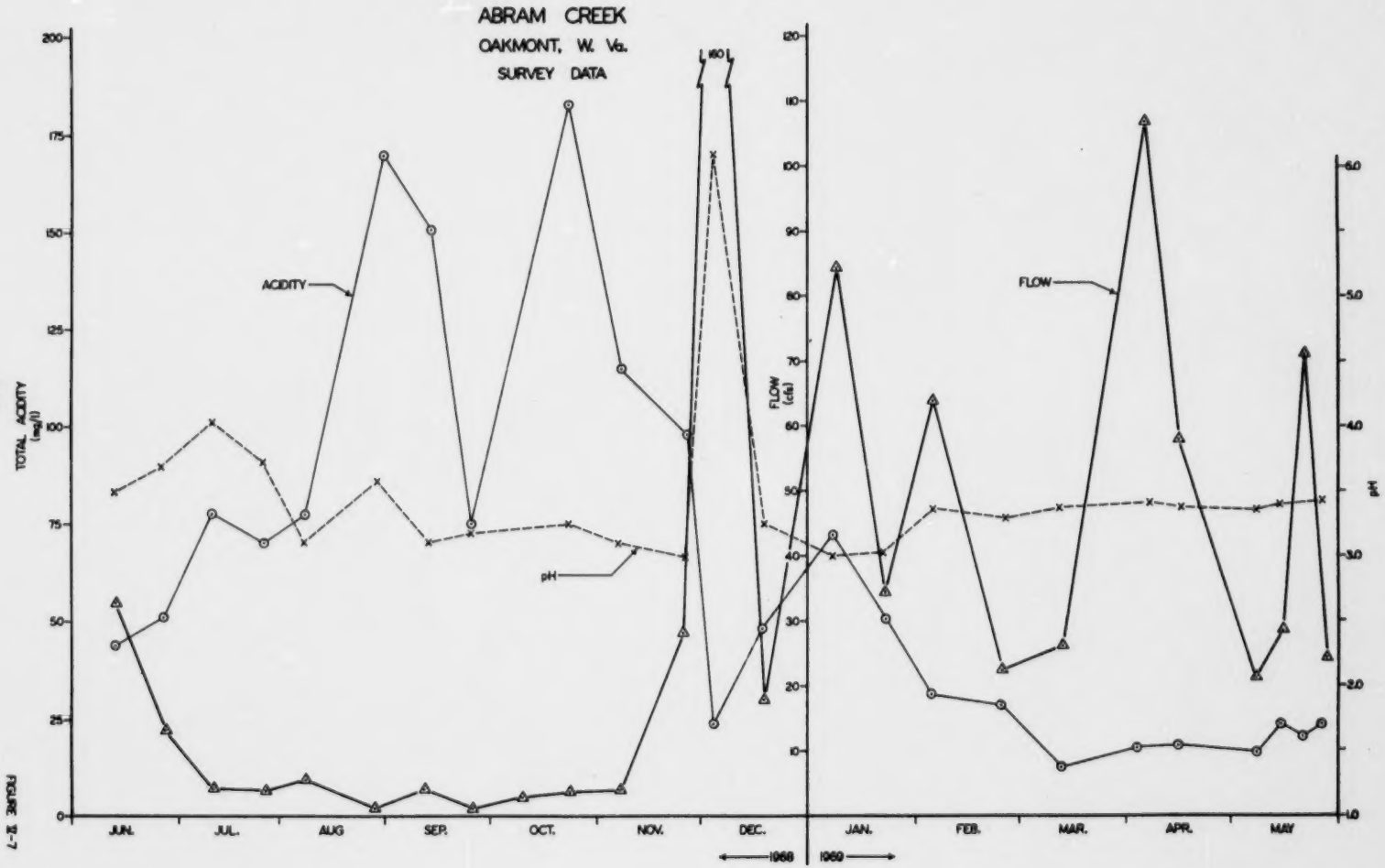

ABRAM CREEK
OAKMONT, W. Va.
SURVEY DATA
ACIDITY
FLOW
pH
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
JUN.
JUL.
AUG
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE II-7

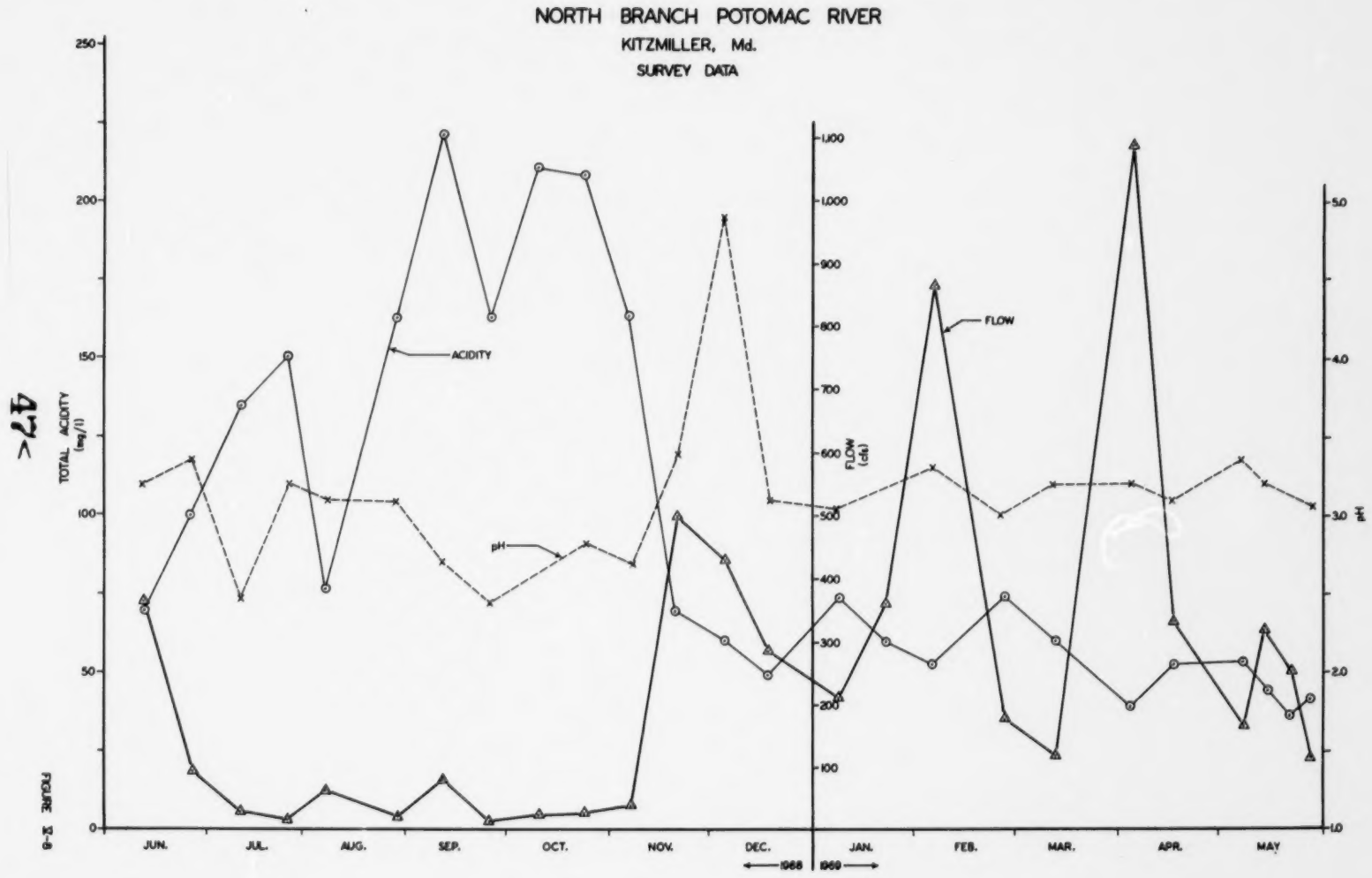

NORTH BRANCH POTOMAC RIVER
KITZMILLER, Md.
SURVEY DATA
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
ACIDITY
FLOW
250
200
150
100
50
0
1,100
1,000
900
800
700
600
500
400
300
200
100
5.0
4.0
3.0
2.0
1.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE 2-8

same difference is due to the sharp break in the acidity-pH relationship as shown in Figure IV-1. Much greater improvement is necessary, though, for this stream reach to comply with the water quality standards.

Even with the reduction in acidity, there is contravention of the present pH standards.

C. KITZMILLER, MARYLAND TO BERYL, WEST VIRGINIA

Water quality data was collected routinely from four stations between Kitzmiller and Beryl. The three tributary watersheds monitored were Three Forks, Elklick, and Piney Swamp Run. Main stem stations were maintained near the site of the U. S. Army Corps of Engineers proposed Bloomington Reservoir Project at Barnum and at Beryl.

1. Three Forks Run (Maryland)

Acidity concentrations between 600 and 700 mg/l in Three Forks Run were measured during low flow periods (Figure V-9). Concentrations of 100 mg/l were observed under high flow conditions.

A direct relationship appears to exist between pH and flow for the Three Forks Run station. The low pH values (2.1 - 2.5) occurred during low flow periods and values in excess of 3.2 were noted when high flows prevailed.

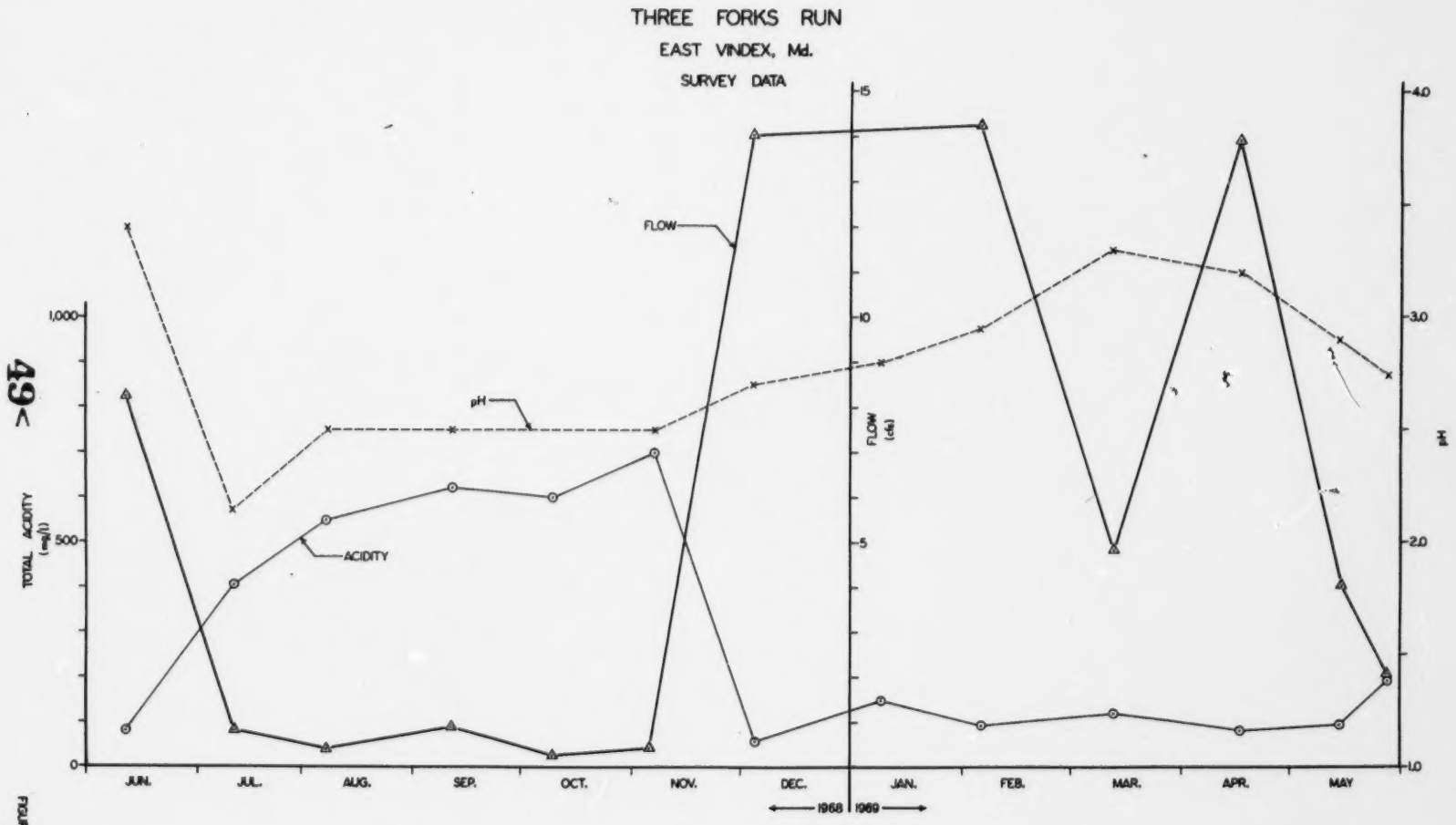

THREE FORKS RUN
EAST VINDEX, Md.
SURVEY DATA
FLOW
pH
ACIDITY
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
1,000
500
0
15
10
5
4.0
3.0
2.0
1.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE 3-9

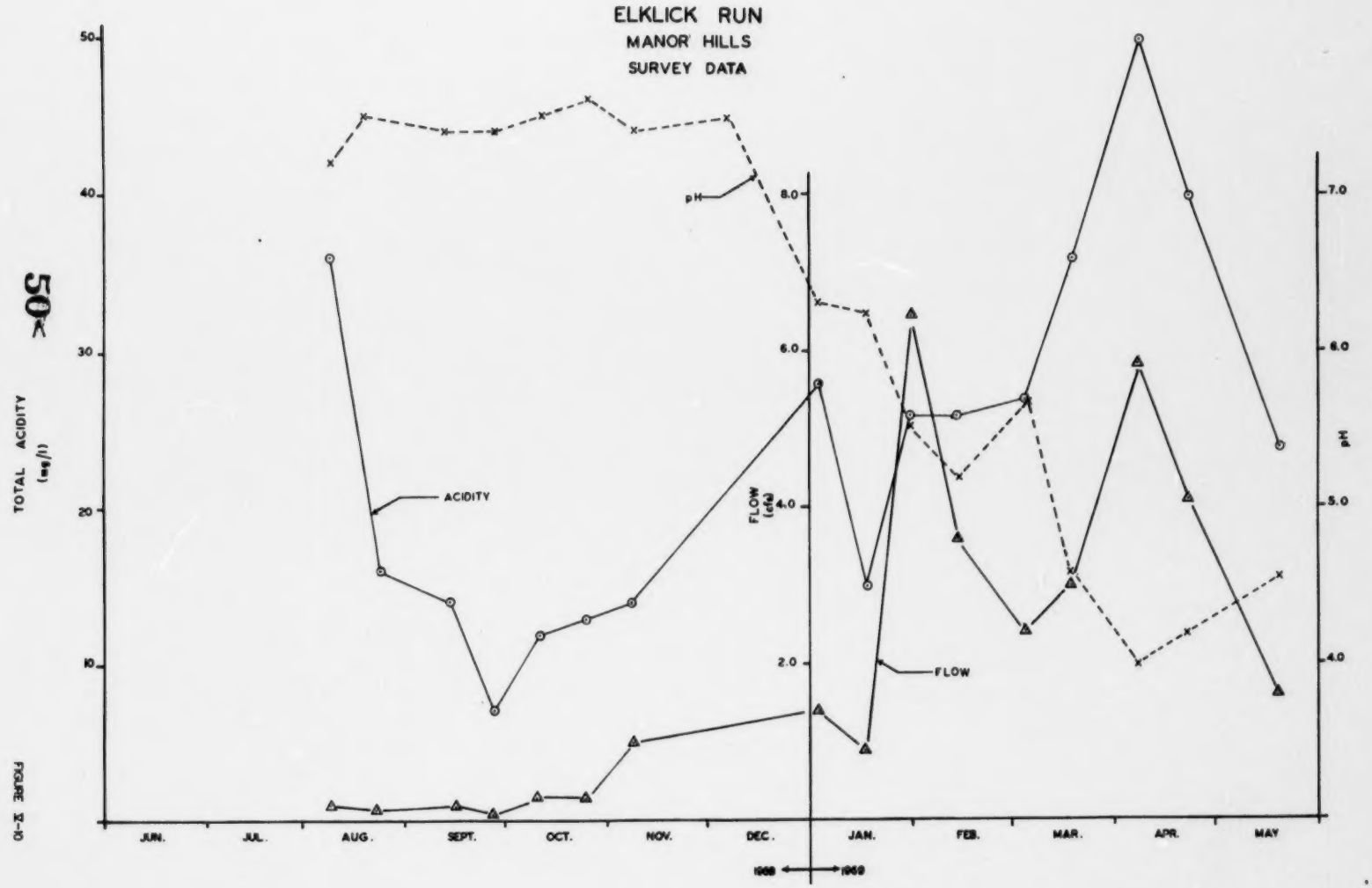

ELKLICK RUN
MANOR HILLS
SURVEY DATA
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
ACIDITY
FLOW
50
40
30
20
10
8.0
6.0
4.0
2.0
7.0
6.0
5.0
4.0
JUN.
JUL.
AUG.
SEPT.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE 12-10

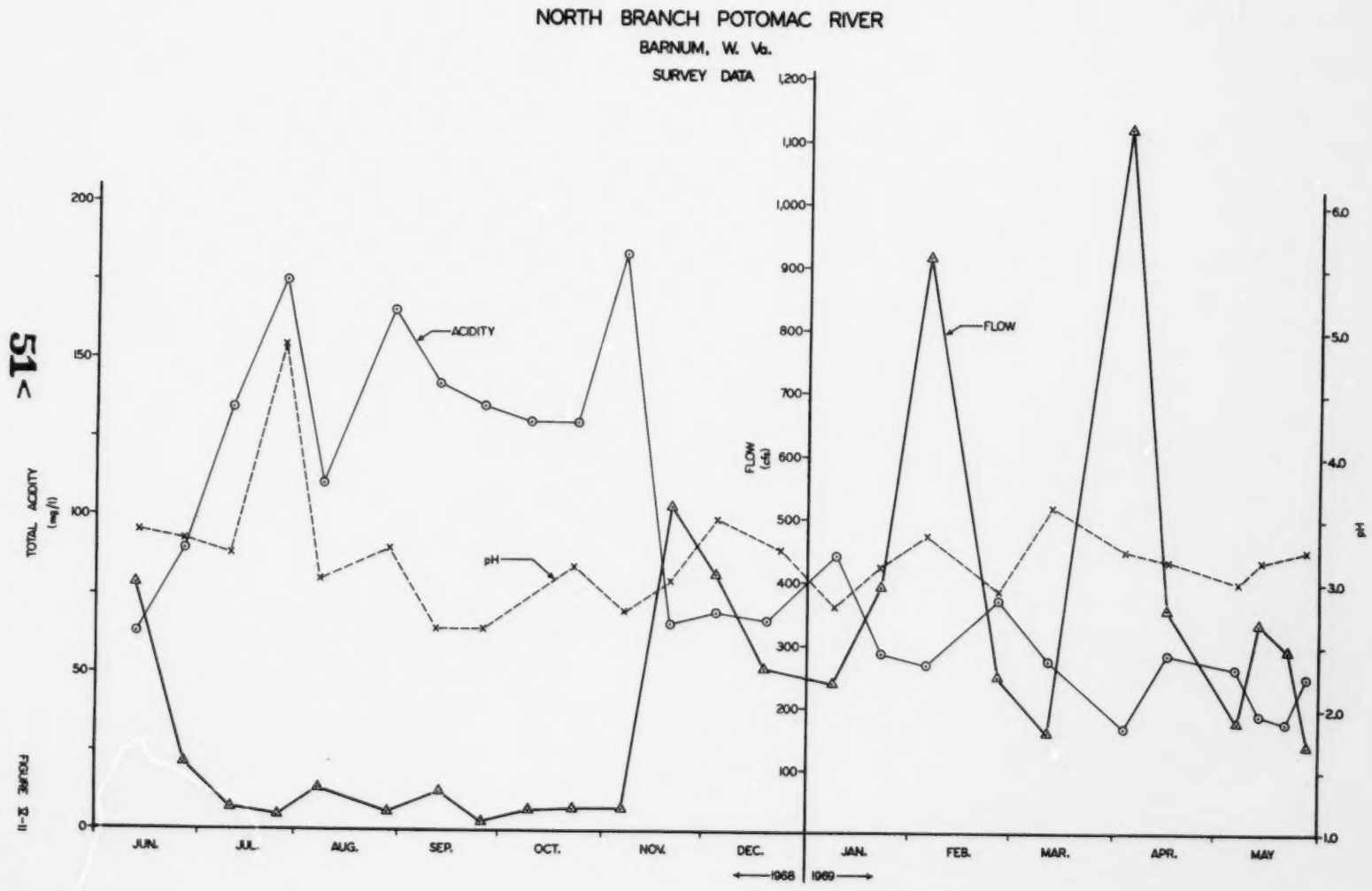


FIGURE II-11

51<

The Maryland standards prescribe a minimum pH criterion of 6.0. for Three Forks Run. The maximum pH observed at the Three Forks station was only 3.3.

2. Elklick Run (MDWR data)

Of the three tributaries discussed in this area, Elklick Run ranks as the least significant in terms of acidity concentration. The acidity concentrations (Figure V-10) have a range from about 8 to 50 mg/l.

A direct acid-flow relationship was observed for the Elklick Run station in contrast to an indirect relationship for most other stations. An exceptionally wide range in pH was noted during the ten month sampling period. Values exceeding the neutrality level, 7.0, were observed continously from August to December. The acidity during the same period was at a minimum. The lowest pH observed was 4.0 which occurred during a high flow - high acid period in April. The unique manner in which pH and acidity varies with flow may possibly be attributed to inactive mines that drain only during wet periods or alkaline mine drainage discharges.

The Maryland stream standards for Elklick Run were contravened during February, March, April, and May of 1969.

3. North Branch at Barnum

Figure V-11 summarized sampling data collected from the North Branch Potomac River at Barnum, West Virginia which is located immediately downstream from the proposed Bloomington Reservoir site. A comparison of the acidity concentration presented in

Figure V-8 for the North Branch Potomac at Kitzmiller and at Barnum indicated a slight improvement in the water quality. The maximum acid concentrations encountered at Barnum were about 180 mg/l while those at Kitzmiller were 220 mg/l, with minimum concentrations of approximately 30 mg/l and 40 mg/l, respectively. At both Barnum and Kitzmiller, peaks in acidity were observed during the late summer and fall months.

The pH levels also indicated a slight improvement. The Kitzmiller station had pH values as low as 2.5, whereas the minimum pH at Barnum was 2.7. This slight improvement in water quality from Kitzmiller to Barnum is probably due to a combination of dilution and natural alkalinity from areas unaffected by mining operations.

Limited iron data were collected at the Barnum station. A tabulation of the analytical results follows:

Date	Total Iron ($Fe_2 + Fe_3$)
6/26/68	1.95 mg/l
9/25/68	1.78 mg/l
11/06/68	4.75 mg/l
11/20/68	2.75 mg/l
12/04/68	3.40 mg/l
12/18/68	1.55 mg/l
1/08/69	4.30 mg/l
1/22/69	1.08 mg/l
2/05/69	3.60 mg/l
2/26/69	3.00 mg/l
3/12/69	2.90 mg/l
4/03/69	1.00 mg/l

Although standards for iron have not been established by the State of Maryland, the values shown on the preceding page are about an order of magnitude higher than recommended levels for municipal and industrial water supply (Chapter VII-A).

Extensive sampling data indicate that the Bloomington Reservoir will definitely impound water of undesirable quality.

4. Piney Swamp Run (West Virginia)

The pH levels in Piney Swamp Run at no time throughout the entire year of sampling exceeded 3.0. The minimum recorded pH value was 2.1. Both the acidity and pH were dependent upon flow to a certain extent.

Acid concentrations in Piney Swamp Run ranged from 100 to 1,000 mg/l (Figure V-12) and were consistently greater than either Three Forks Run or Elklick Run. Elk Run is the only stream in the North Branch Potomac basin having a greater acid concentration.

The water quality of Piney Swamp Run does not comply with West Virginia's stream standards.

5. North Branch at Beryl, West Virginia

The effects of Piney Swamp Run and possibly other acid streams on the North Branch Potomac can be readily seen by examining Figure V-13 which presents the water quality sampling data collected at Beryl. The maximum acidity concentration at Barnum was about 190 mg/l while at Beryl it had increased to about 220 mg/l. The pH at Beryl varied between 2.7 and 3.6.

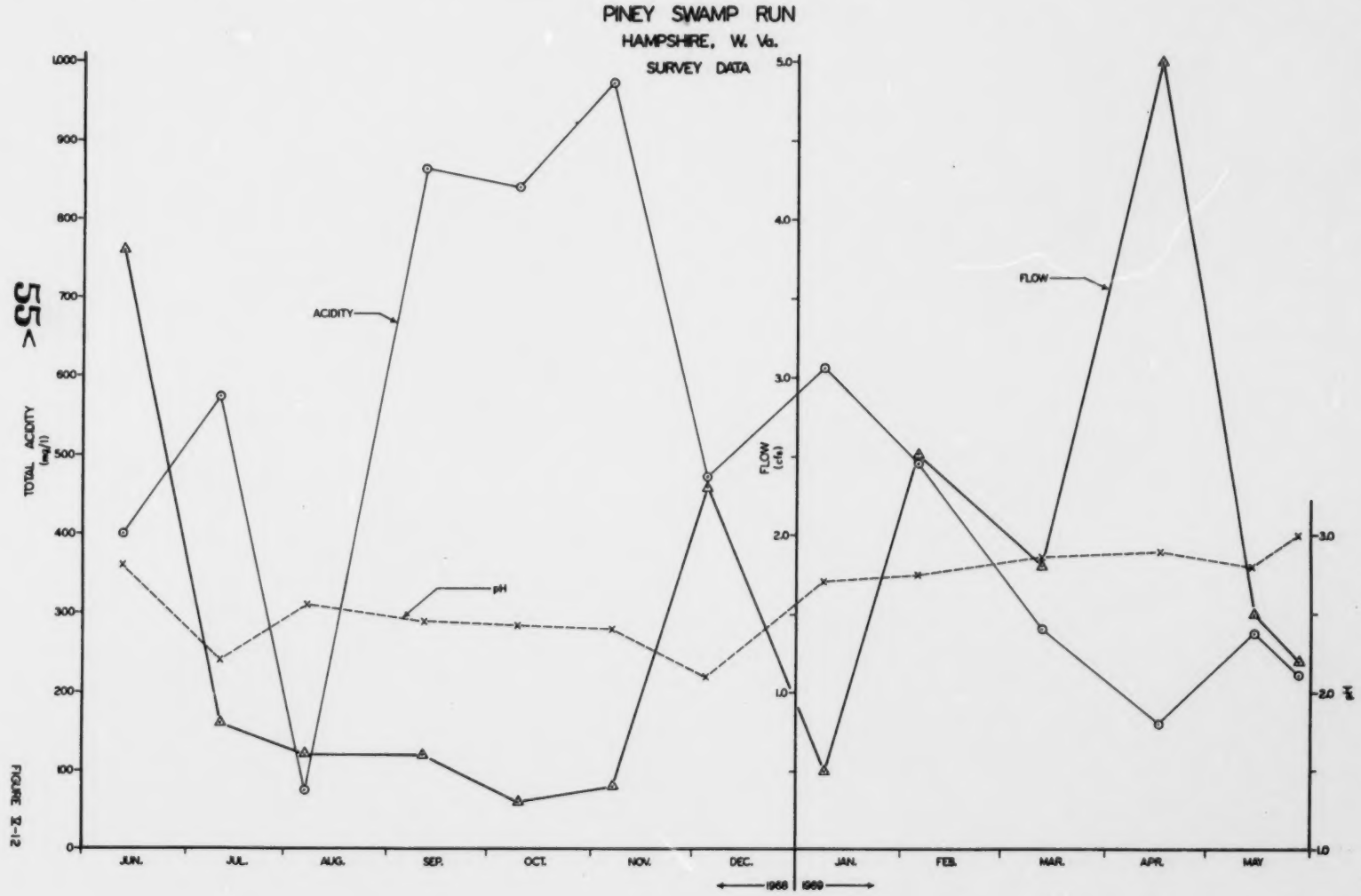

PINEY SWAMP RUN
HAMPSHIRE, W. Va.
SURVEY DATA
ACIDITY
FLOW
pH
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
1000
900
800
700
600
500
400
300
200
100
0
5.0
4.0
3.0
2.0
1.0
3.0
2.0
1.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE X-12

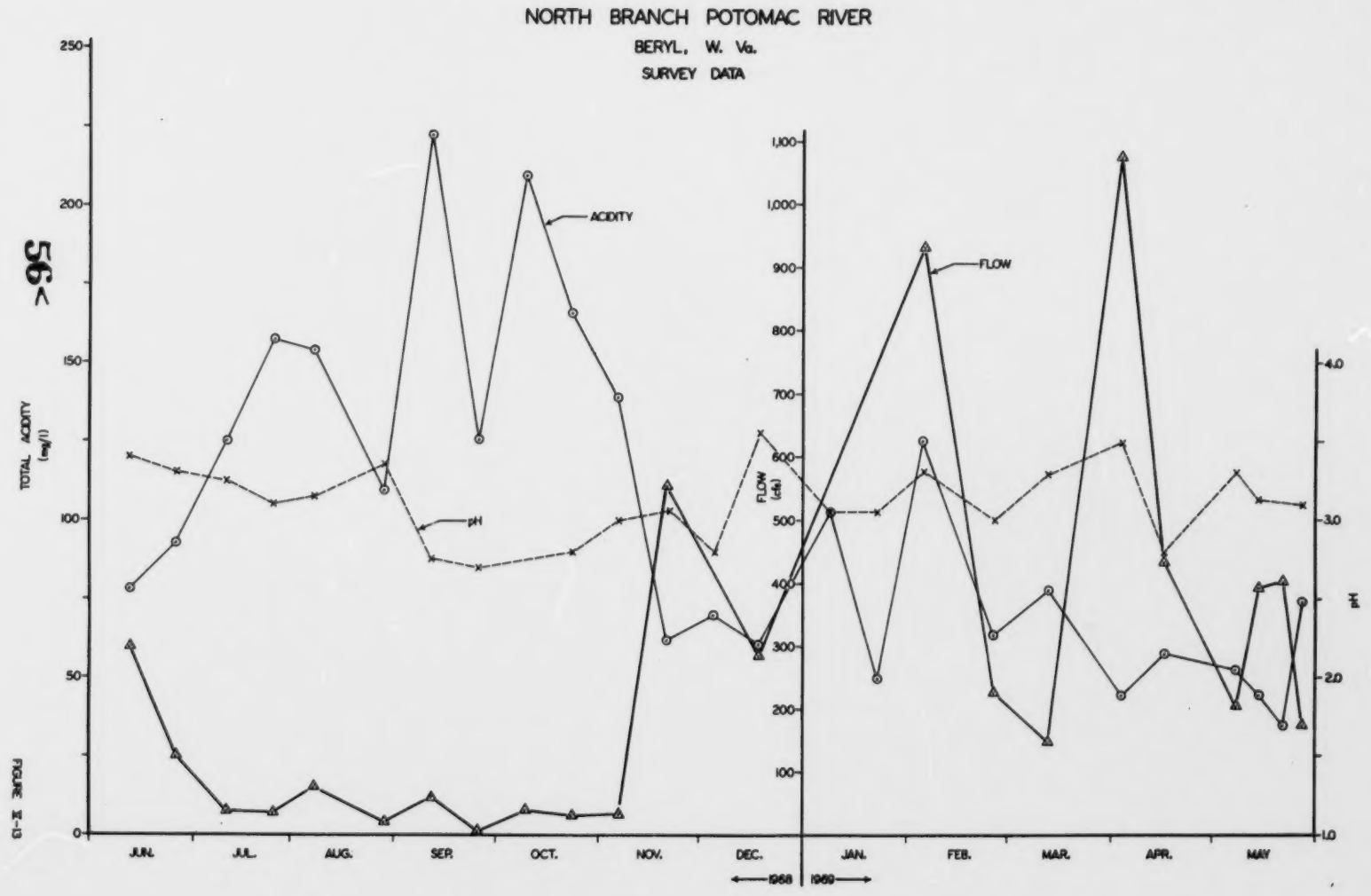

NORTH BRANCH POTOMAC RIVER
BERYL, W. Va.
SURVEY DATA
ACIDITY
FLOW
pH
TOTAL ACIDITY (mg/l)
FLOW (cfs)
pH
250
200
150
100
50
0
1,100
1,000
900
800
700
600
500
400
300
200
100
4.0
3.0
2.0
1.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE II-13

Similar to the upper North Branch stations, the lowest pH values were observed during low flow - high acid periods. A comparison of Figures V-11 and V-13 indicate many similarities in the average magnitude and annual variation pattern of pH at Barnum and Beryl.

The water quality of the North Branch Potomac between Kitzmiller and Beryl does not undergo any significant change from the standpoint of pH and acid concentration. The adverse effects of Three Forks Run and Piney Swamp Run are diminished somewhat by the flows of small alkaline tributaries; nevertheless, the water quality in this entire reach continues to contravene Maryland's stream standards.

D. BERYL TO KEYSER, WEST VIRGINIA

Four surveillance stations were maintained in the North Branch Potomac basin between Beryl and Keyser. One station on Georges Creek, two on Savage River, both of which are tributary streams, and one on the North Branch at Keyser were maintained within this area.

1. Savage River (Maryland)

Savage River flows are regulated by Savage I Reservoir to maintain a predetermined minimum discharge of 93 cfs into the North Branch at Luke, Maryland. The only major source of mine drainage in this watershed is Aaron Run, a small creek between Savage I Reservoir and the confluence with the North Branch.

Survey data for the station above Aaron Run (Figure V-14) show an extremely variable net alkalinity concentration, ranging from

-27 mg/l to +73 mg/l. Savage River above Aaron Run is usually alkaline. Only occasionally were acidic conditions noted. The pH levels at this station were generally greater than 6.0.

Survey data for Savage River near its confluence with the North Branch, downstream from Aaron Run (Figure V-15), indicate lower net alkalinity when compared to the upstream station. The net alkalinity values ranged from -27 mg/l to +73 mg/l at the upstream station with the downstream station exhibiting a range from -38 mg/l to +32 mg/l.

The pH values recorded near the mouth of the Savage River were somewhat lower than those upstream which also indicates water quality degradation. A minimum pH of 5.1 was observed near the confluence whereas upstream values were never less than 5.7.

The pH levels during the months of July and October were under 6.0, the minimum pH standard for the Savage River.

The alkalinity content of the Savage River appears to be greater during dry weather than during wet weather periods. This may possibly be attributed to the following:

a. Aaron Run is more likely to contribute a significant acid loading during wet weather, and

b. Savage River drains a limestone region above the reservoir and the increased percentage of groundwater inflow during dry weather probably carries greater alkalinity concentrations into the reservoir and thence into the release flow.

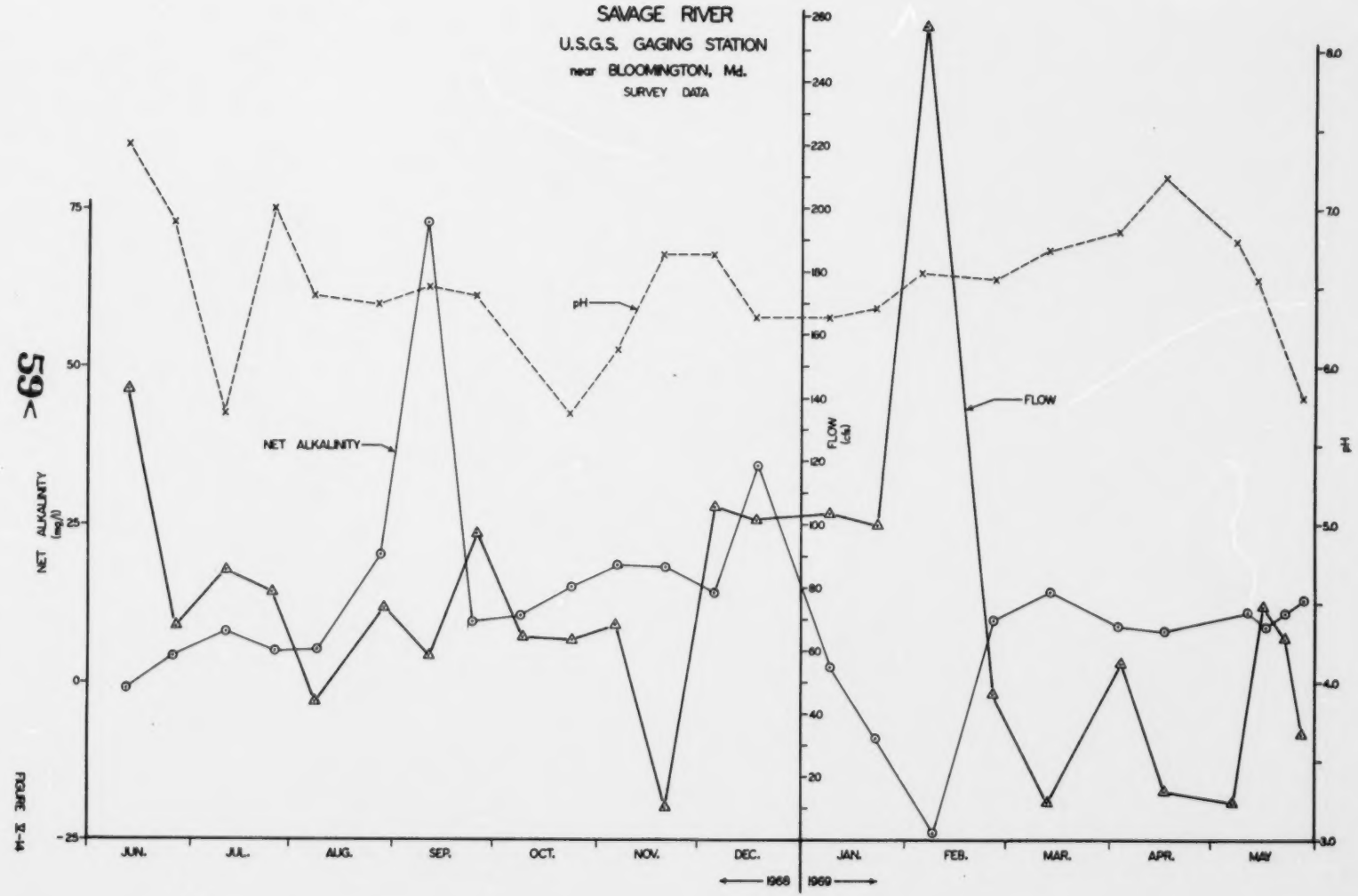

SAVAGE RIVER
U.S.G.S. GAGING STATION
near BLOOMINGTON, Md.
SURVEY DATA
NET ALKALINITY (mg/l)
FLOW (cfs)
pH
NET ALKALINITY
FLOW
75
50
25
0
-25
260
240
220
200
180
160
140
120
100
80
60
40
20
8.0
7.0
6.0
5.0
4.0
3.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE II-14

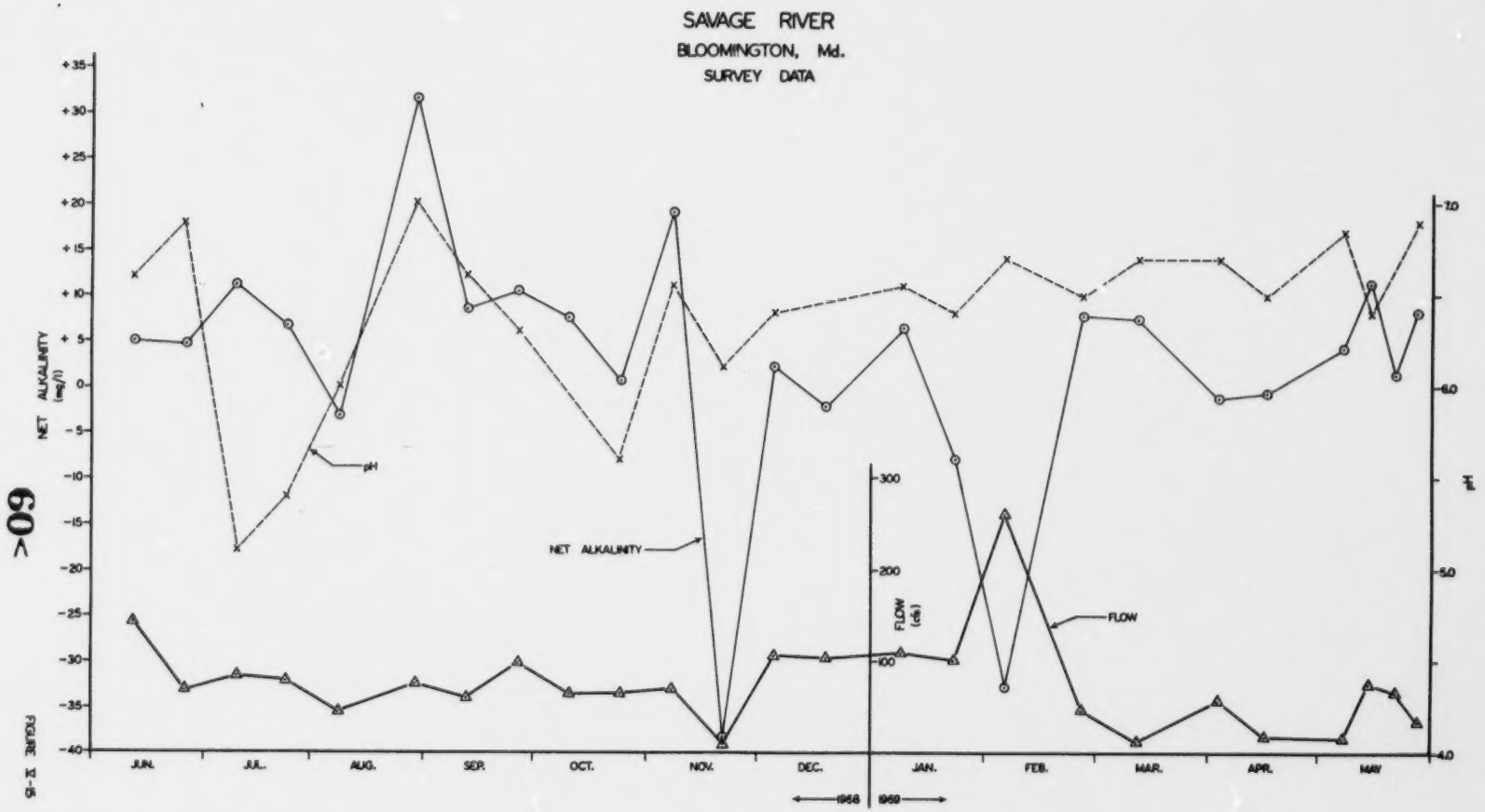


FIGURE IX-15

>09

2. Georges Creek

Net alkalinity for the station on Georges Creek varied from about -26 mg/l to +4 mg/l. The pH varied from 4.2 to 6.5 with the lower range occurring most frequently. As can be seen in Figure V-16, a decrease in flow resulted in an increase in pH and had very little effect on net alkalinity.

Based on the limited amount of data available, Georges Creek contributes a more acidic flow to the North Branch than Savage River; however, neither compares with the acid contributions of most tributary streams previously discussed.

3. North Branch at Keyser

The North Branch Potomac River at Keyser, West Virginia represents the most downstream sampling station of this survey (Figure V-17). Although sampling was conducted only from February through May 1969, the data (Figure V-17) were sufficient to indicate that considerable recovery had occurred.

During comparable periods of the year, the maximum acidity between Beryl and Keyser had decreased from 125 mg/l to 65 mg/l and the minimum pH had increased from 2.8 to 3.5. The acidity and pH had both fluctuated widely at Keyser. In a few instances, the net alkalinity was positive and pH levels were greater than 6.0.

The recovery in water quality observed at Keyser may be attributed to the highly alkaline loads discharged from the West Virginia Pulp and Paper Company at Luke, and the Upper Potomac River Commission's waste treatment facility at Westernport. Together

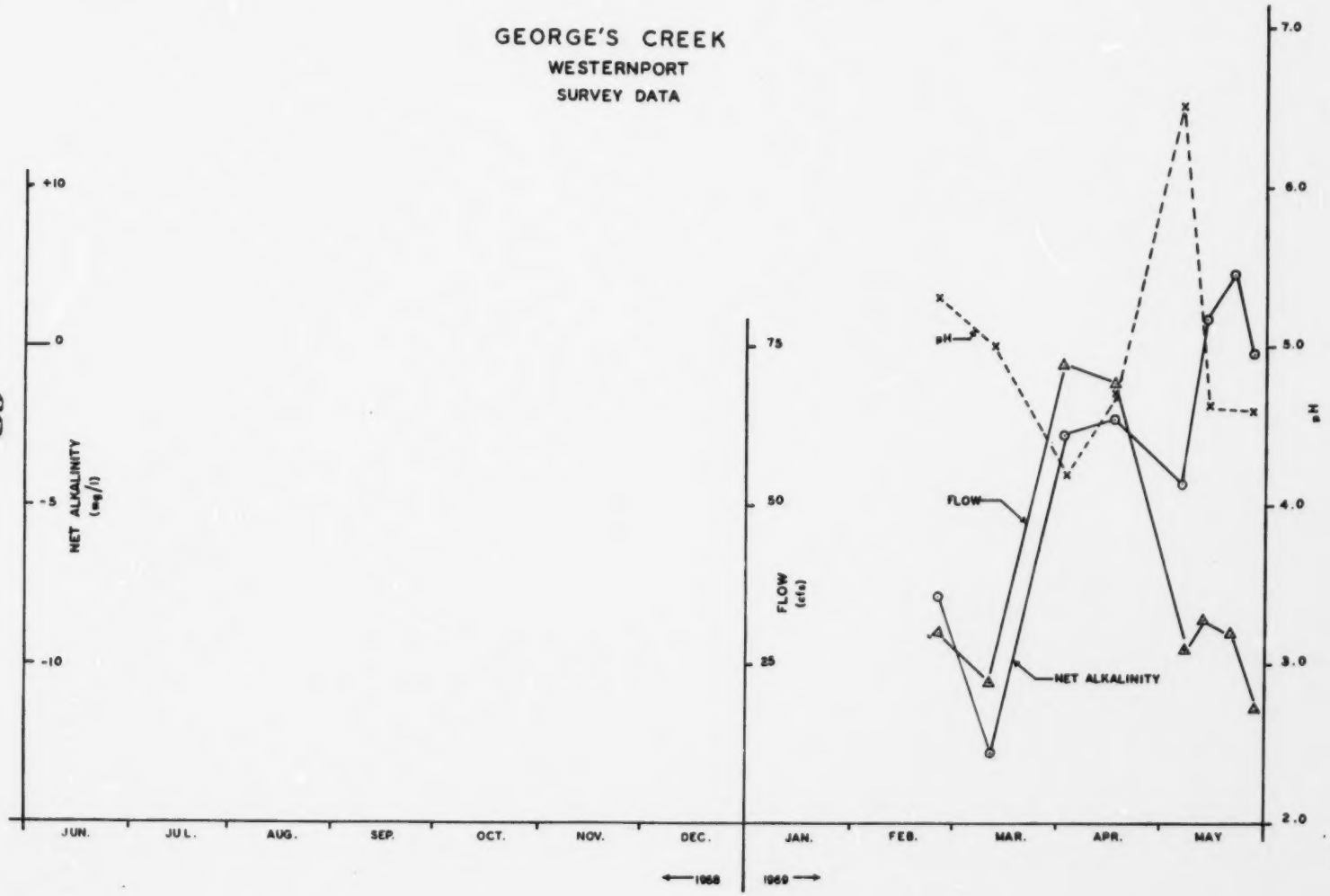

GEORGE'S CREEK
WESTERNPORT
SURVEY DATA
NET ALKALINITY (mg/l)
+10
0
-5
-10
FLOW (cfs)
75
50
25
pH
7.0
6.0
5.0
4.0
3.0
2.0
FLOW
NET ALKALINITY
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE E-16

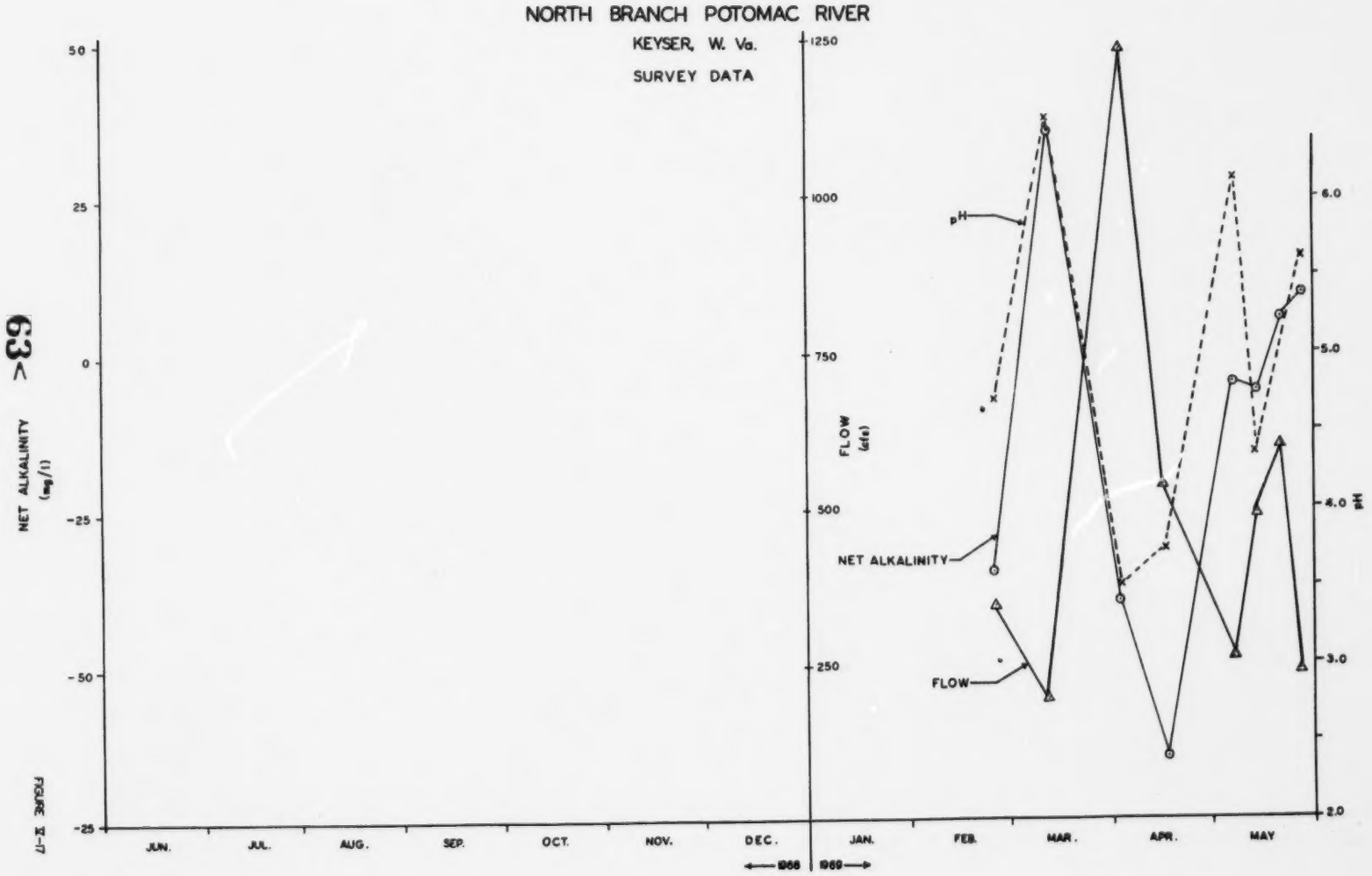

NORTH BRANCH POTOMAC RIVER
KEYSER, W. Va.
SURVEY DATA
NET ALKALINITY (mg/l)
FLOW (cfs)
pH
NET ALKALINITY
FLOW
50
25
0
-25
-50
-25
1250
1000
750
500
250
6.0
5.0
4.0
3.0
2.0
JUN.
JUL.
AUG.
SEP.
OCT.
NOV.
DEC.
JAN.
FEB.
MAR.
APR.
MAY
1968
1969

FIGURE II-17

these discharges provide upwards of 40,000 lbs/day total alkalinity. The pulp mill's water withdrawal for processing purposes accounts for an additional acidity reduction in the North Branch of approximately 17,000 lbs/day. The alkalinity from various sources between Beryl and Keyser greatly overshadows the acidity contributed by Savage River and Georges Creek.

E. SUMMARY OF 1968-69 ACIDITY DATA

A summary of the acidity data for the North Branch Potomac River is presented in isopleth* form in Figure V-18. This indicates that maximum acid concentrations for any given station generally occurred during the summer and fall months while minimum concentrations were observed during the spring months.

The sampling station at Steyer produced higher acid concentrations than other stations along the Potomac for comparable periods of the year. Maximum concentrations approached 600 mg/l whereas maximum concentrations at Kitzmiller, Barnum, and Beryl were approximately 210 mg/l, 160 mg/l, and 160 mg/l, respectively. Even during the winter months average acidity concentrations at Steyer were generally greater than 100 mg/l.

* An isopleth, which offers a complete graphical presentation of water quality with respect to location and time along the stream is useful for depicting variations of a parameter at a given location for a specific time or for a given time period along the main stem. The isopleths were constructed by plotting all data for a given station along the stream for the twelve-month period. A smooth curve was fitted to these data as representative of "average" conditions during the entire survey period.

It should also be noted that the water quality at Steyer during the winter period was comparable to summer conditions at Barnum and Beryl which further indicate the extreme spatial and temporal acid distribution in the North Branch Potomac.

Water quality data (August 1969), collected subsequent to the survey data, presented in Chapters V and VI showed pH levels of 3.3 to 3.6 in the North Branch Potomac River at Cumberland, Maryland. These exceptionally low pH's, which were the result of a reduction in alkalinity from Westvaco and an acid "slug" produced by excessive rainfall in the disturbed areas of the upper basin, caused an extensive fishkill in the lower reaches of the North Branch near Oldtown, Maryland. Similar water quality problems will continue to be encountered downstream from Cumberland during high runoff periods.

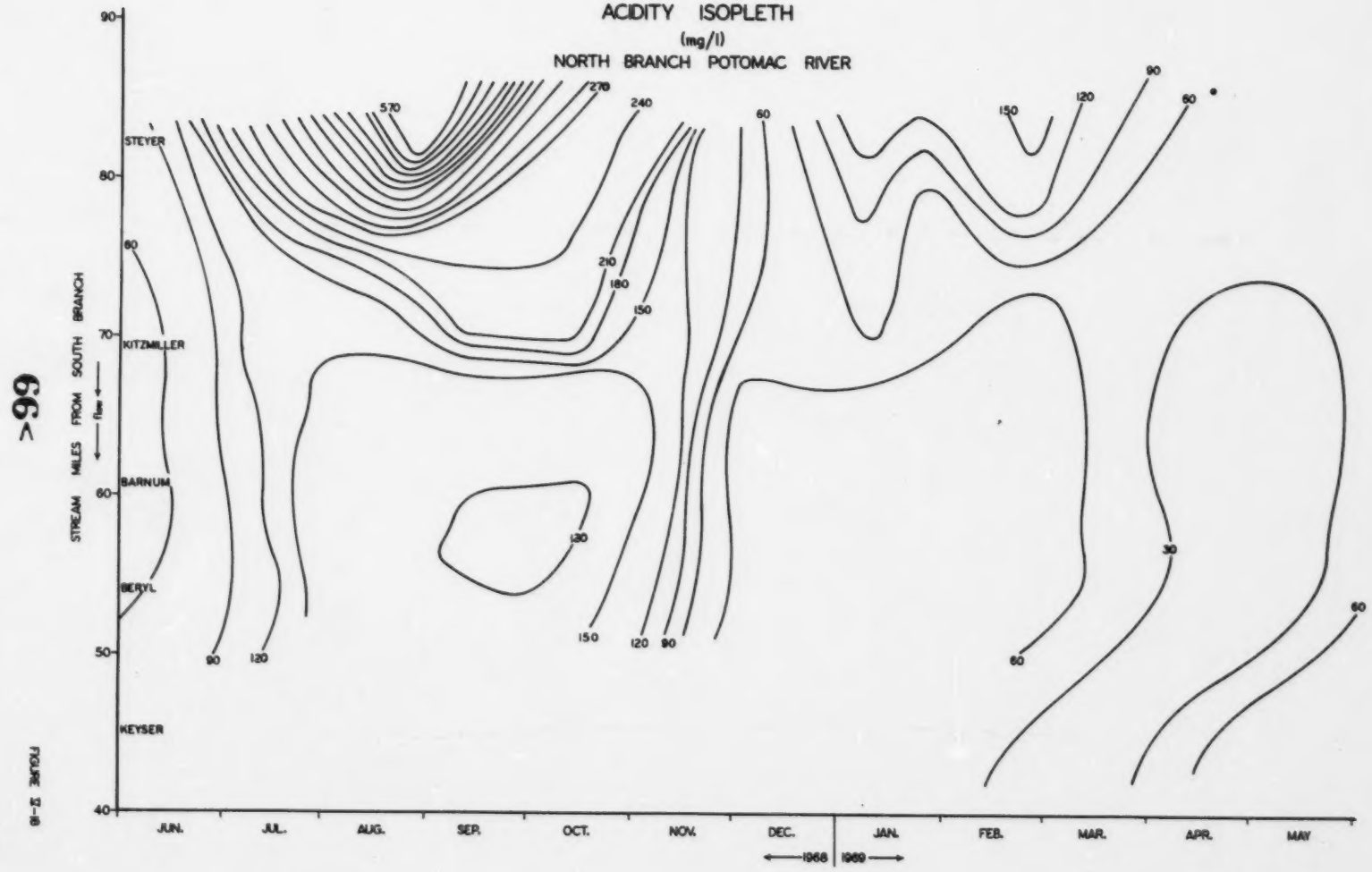


FIGURE 21-18

>99

CHAPTER VI

MINE DRAINAGE TRENDS AND DELINEATION OF ACID LOADINGS

A. HISTORICAL TRENDS IN pH AND ACIDITY FOR NORTH BRANCH ABOVE LUKE, MARYLAND

Figure VI-1 presents mean monthly pH data for a ten-year period of record as compiled by the West Virginia Pulp and Paper Company for the North Branch above Luke. Stream flow data are shown in Figure VI-2. An examination of Figures VI-1 and VI-2 indicates that both pH and flow vary in an annual cyclical pattern. Further analysis of these patterns indicates that pH levels generally reach a maximum during the late winter and spring months. Flows during this period of the year also have a tendency to be high. Conversely, minimum pH levels generally occurred during the late summer and early fall months when flows were at a minimum.

For the ten-year period, the average annual pH also appears to be directly related to the average annual flows. For example, the extremely dry years of 1959 and 1965-66 generally showed lower pH values. Conversely, the relatively wet year of 1963 resulted in higher pH values some of which approached a neutral pH of 7.0.

In Figure VI-3, the long-term acidity data, also compiled by the West Virginia Pulp and Paper Company, reflect the increase in mining activity as reported in Chapter III. The average acid concentration increased from about 3.0 mg/l in late 1950 to over 20 mg/l in 1968.

HISTORICAL pH TREND

NORTH BRANCH POTOMAC RIVER

LUKE, Md.

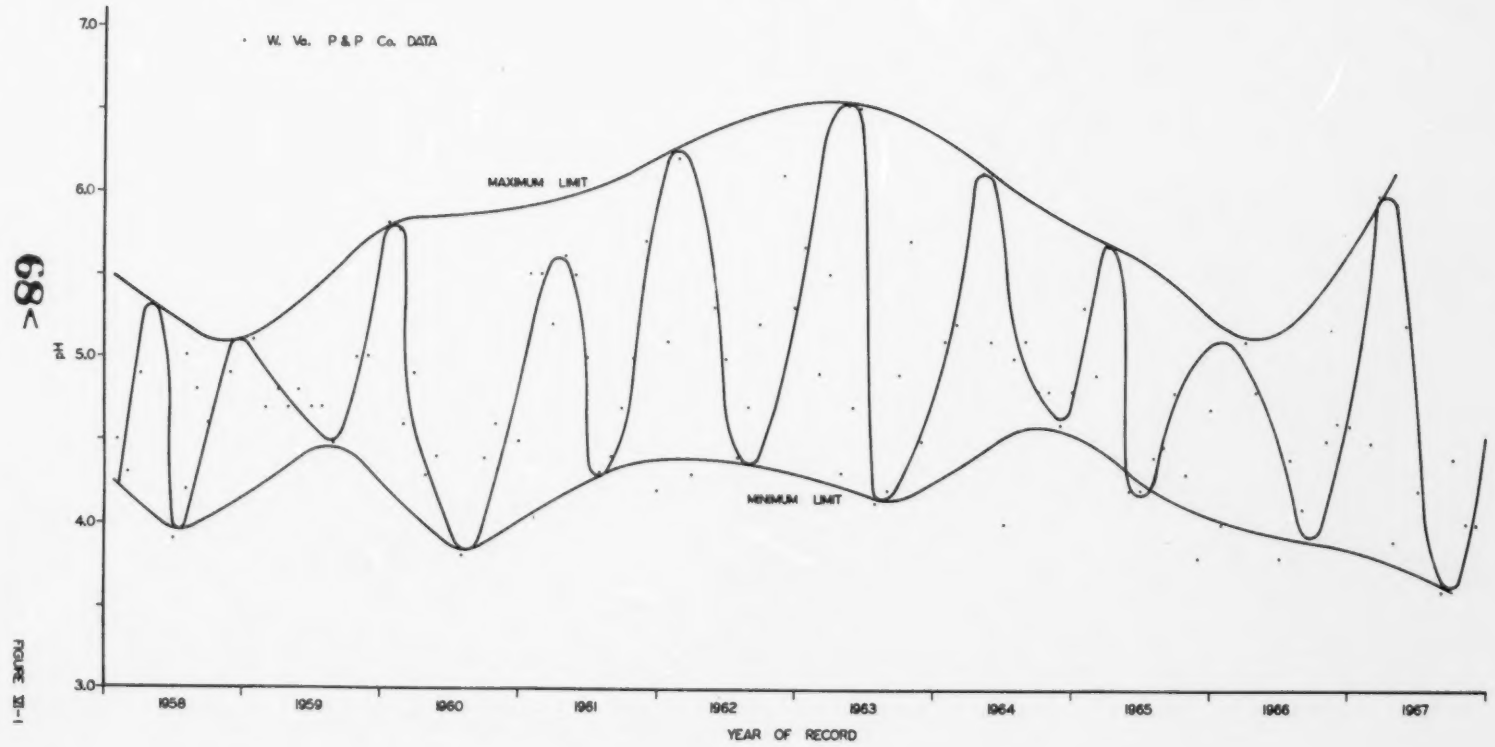


FIGURE IX-1

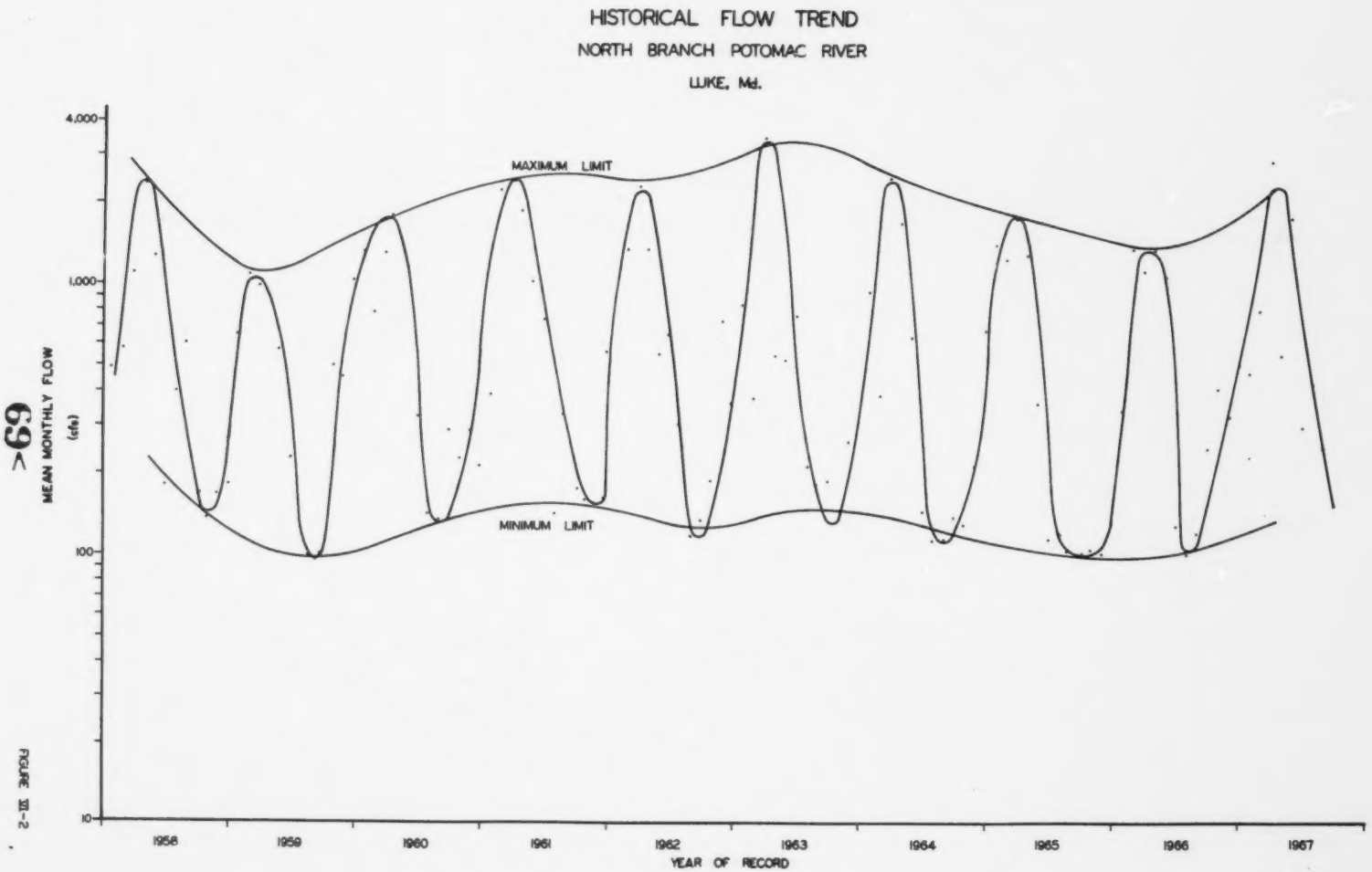
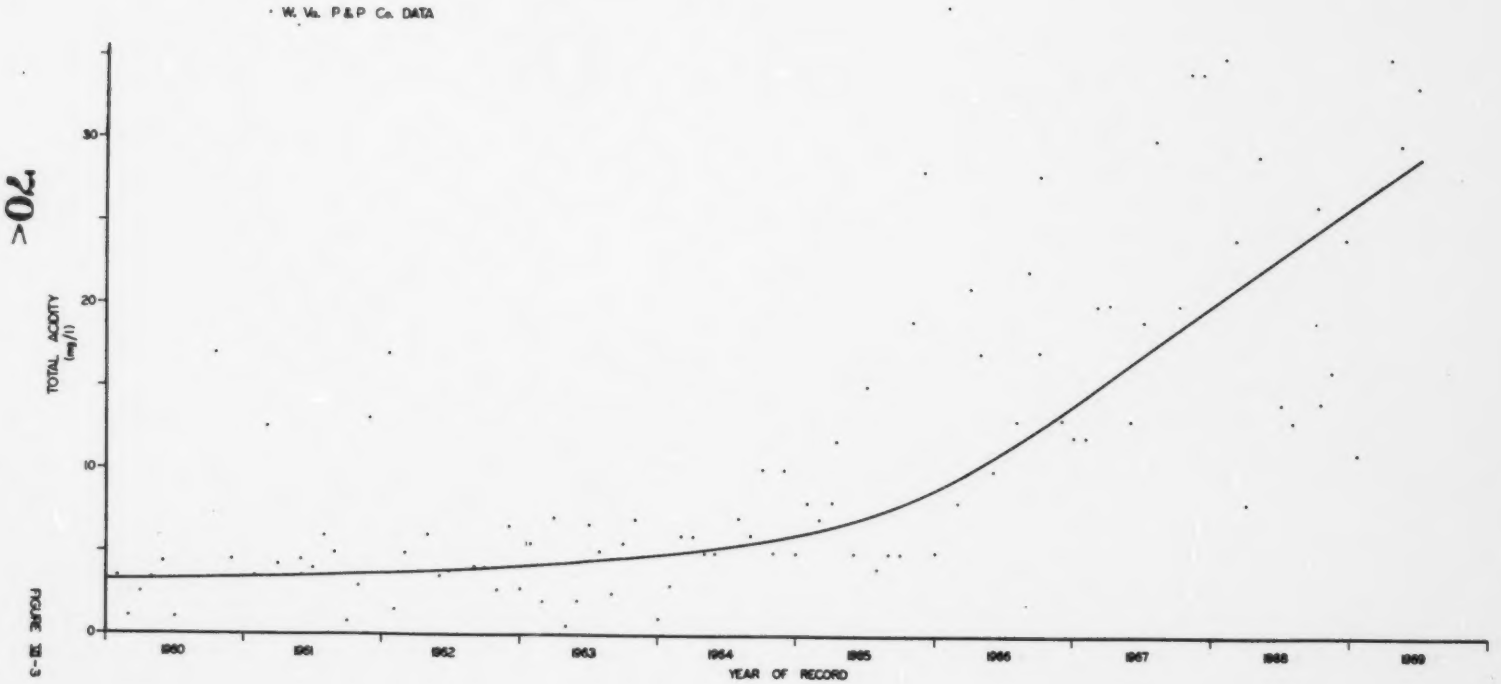

HISTORICAL FLOW TREND
NORTH BRANCH POTOMAC RIVER
LUKE, Md.
4,000
1,000
100
10
MEAN MONTHLY FLOW (cfs)
MAXIMUM LIMIT
MINIMUM LIMIT
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
YEAR OF RECORD

FIGURE III-2

HISTORICAL ACIDITY TREND
NORTH BRANCH POTOMAC RIVER
LUKE, Md.



>70%

FIGURE III-5

While a quantitative comparison cannot be made with CTSL data because of differences in analytical procedures and the effect of flow augmentation from Savage I Reservoir, the data nevertheless indicate a marked deterioration in water quality since 1965. Associated with this increase in average acid concentrations was an increase in the range of acidity.

B. DELINEATION OF ACIDITY LOAD

The tabulations of acidity loading for the four stations on the main stem (Steyer, Kitzmiller, Barnum, and Beryl) are presented in Tables VI-1, VI-2, VI-3, and VI-4, respectively. The Steyer station is in area A, Kitzmiller in area B, and Barnum and Beryl in area C as presented in the previous chapter.

In area A, the watersheds of Elk Run, Laurel Run, and Buffalo Creek, with 28.2 percent of the drainage area at Steyer, produced 70 percent of the acid loading. As can be seen in Table VI-1, over 39 percent of this loading was from Elk Run.

For area B, as presented in Table VI-2, tributary sampling stations with 55.9 percent of the drainage area yielded 88 percent of the acid at Kitzmiller. Of the 77,700 lbs/day measured at Kitzmiller, 72 percent originated in area A from the Elk Run, Laurel Run, and Buffalo Creek watersheds.

As exhibited in Tables VI-3 and VI-4, the tributary contributions also reflect the predominant influence of the three watersheds in area A on the loadings in area C. Within area C, the total acid

loadings increased by 22 percent from 94,000 lbs/day at Barnum to 119,000 lbs/day at Beryl.

The following five watersheds, which have a total drainage area of 116 square miles, produced over 65 percent of the acid load at Beryl.

Watershed	Acid Loading lbs/day	Location
Elk Run	35,700	West Virginia
Buffalo Creek	15,300	West Virginia
Laurel Run	12,900	Maryland
Abram Creek	8,300	West Virginia
Stony River	4,300	West Virginia

Of the five watersheds listed above Elk Run, Buffalo Creek, and Laurel Run, with a combined drainage area of 20.6 square miles, produce over 54 percent of Beryl's acid loading.

The tributary contributions and resulting main stem loadings as presented in Figure VI-4 also demonstrated the influence of the mine drainage from area A. The close agreement between the calculated and observed acid loadings at main stem stations above Barnum indicate that the primary sources of acid in this area were identified. However, between Barnum and Beryl an additional 25,000 lbs/day of acid were measured. The two streams within this reach that were monitored (an unnamed tributary and Piney Swamp Run) contained a combined acid load of 4,700 lbs/day resulting in approximately

TABLE VI-1

TRIBUTARY CONTRIBUTIONS UPSTREAM FROM STEYER, MARYLAND
1968-1969

Watershed	D. A. (sq. mi.)	Percent of Steyer's D.A.	Mean Flow (cfs)	Percent of Steyer's Flow	Mean Acid Load (lb/day)	Percent of Steyer's Acid Load
Elk Run	3.8	5.2	2.1	1.2	35,700	39
Laurel Run	7.5	10.3	16.0	8.8	12,900	14
Buffalo Creek	9.3	12.7	20.0	11.0	15,300	17
TRIBUTARY TOTALS	20.6	28.2	38.1	21.0	63,900	70
STEYER	73	100	183.0	100.0	91,000	100

TABLE VI-2

TRIBUTARY CONTRIBUTIONS UPSTREAM FROM KITZMILLER, MARYLAND

1968-1969

Watershed	D.A. (sq.mi.)	Percent of Kitzmiller's D.A.	Mean Flow (cfs)	Percent of Kitzmiller's Flow	Mean Acid Load (lb/day)	Percent of Kitzmiller's Acid Load
Elk Run	3.8	1.7	2.1	<1.0	35,700	40
Laurel Run	7.5	3.3	16.0	4.1	12,900	15
Buffalo Creek	9.3	4.1	20.0	5.1	15,300	17
Stony River	48.8	29.1	128.0	32.7	4,500	5
Lostland Run	9.2	4.1	8.0	2.0	1,000	1
Abram Creek	47.3	21.0	60.0	15.3	8,300	10
TRIBUTARY TOTALS	125.9	55.9	234.1	59.2	77,700	88
KITZMILLER	225	100	392	100	88,000	100

TABLE VI-3

TRIBUTARY CONTRIBUTIONS UPSTREAM FROM BARNUM, WEST VIRGINIA

1968-1969

Watershed	D.A. (sq.mi.)	Percent of Barnum's D.A.	Mean Flow (cfs)	Percent of Barnum's Flow	Mean Acid Load	Percent of Barnum's Acid Load
Elk Run	3.8	1.4	2.1	1.0	35,700	38
Laurel Run	7.5	2.8	16.0	3.7	12,900	14
Buffalo Creek	9.3	3.5	20.0	4.6	15,300	16
Stony River	48.8	18.4	128.0	29.8	4,500	5
Lostland Run	9.2	3.5	8.0	1.9	1,000	1
Abram Creek	47.3	17.8	60.0	14.0	8,300	9
Three Forks Run	7.8	2.9	6.0	1.4	3,300	4
Elklick Run	3.7	1.4	2.0	1.0	340	1
TRIBUTARY TOTALS	137.4	51.7	242.1	55.4	81,340	87
BARNUM	266	100	430	100	94,000	100

TABLE VI-4

TRIBUTARY CONTRIBUTIONS UPSTREAM FROM BERYL, WEST VIRGINIA

1968-1969

Watershed	D. A. (sq.mi.)	Percent of Beryl's D.A.	Mean Flow (cfs)	Percent of Beryl's Flow	Mean Acid Load (lbs/day)	Percent of Beryl's Acid Load
Elk Run	3.8	1.3	2.1	< 1.0	35,700	30
Laurel Run	7.5	2.6	16.0	3.5	12,900	11
Buffalo Creek	9.3	3.2	20.0	4.3	15,300	13
Stony River	48.8	17.0	128.0	27.6	4,500	4
Lostland Run	9.2	3.2	8.0	1.7	1,000	< 1
Abram Creek	47.3	16.5	60.0	13.0	8,300	7
Three Forks Run	7.8	2.7	6.0	1.3	3,300	3
Elklick Run	3.7	1.3	2.0	< 1.0	340	< 1
Unnamed Trib.	0.5	< 1.0	< 1.0	< 1.0	1,500	1
Piney Swamp Run	4.8	1.7	1.7	< 1.0	3,200	3
TRIBUTARY TOTALS	142.7	49.5	243.8	51.4	86,000	73
BERYL	287	100	463	100	119,000	100

20,000 lbs/day of acidity attributable to the remaining portion of the drainage area. A prorating of this acidity based upon the respective drainage areas in Maryland and West Virginia indicates that 1,500 lbs/day originates in West Virginia and 18,500 lbs/day is contributed by watersheds in Maryland.

All of the tributary streams in West Virginia which were monitored contribute approximately 68,500 lbs/day (58% of Beryl's loading) of total acidity to the North Branch Potomac River. The monitored streams in Maryland contribute an average acid load of 17,600 lbs/day (15% of Beryl's loading) and by the difference method described previously, the watersheds on the Maryland side of the North Branch between Barnum and Beryl contribute an estimated acid load of 18,500 lbs/day (16% of Beryl's loading). By prorating the 13,000 lbs/day of acid which enter the North Branch directly or via unmonitored tributary streams above Barnum, the total estimated acid loads contributed by Maryland and West Virginia amount to 39,000 lbs/day (33% of Beryl's loading) and 79,000 lbs/day (67% of Beryl's loading), respectively.

Based upon reconnaissance studies in the area and visual observations, it appears that in West Virginia active mining operations contribute most of the acid drainage. The comprehensive study conducted by the State of Maryland to inventory all known mines disclosed that 22 mines had active status and 135 mines were inactive. Of the active mines 15 were found to be draining and of the inactive mines 71 were draining.

C. REGRESSION STUDIES

The discussions in Section V present an inverse relationship between acidity concentration and stream flow. It therefore follows that some relationship should exist between acid loading and stream flow. A series of linear and non-linear regression analyses were performed based upon various standard equations to determine which would best describe the data. A comparison of the correlation coefficients for each equation resulted in the following expression:

$$L = a_1 Q^b \qquad \ldots\ldots\ldots \text{VI-1}$$

This may be transformed to:

$$\log_{10} L = a + b \log_{10} Q \qquad \ldots\ldots\ldots \text{VI-2}$$

Where:

L = acid loading (lbs/day)

Q = river discharge (cfs)

a = constant defining the y intercept on a log-log plot ($a_1 = 10^a$)

b = exponent defining the slope of the curve in the form of Eq VI-2

The above equation is an exponential function which plots as a straight line on log-log paper. Of particular importance in this equation is the "b" term, or slope, since it represents the rate at which acidity is increasing for any given flow.

A practical interpretation of Equation VI-1 reveals that the lower flow range produces a maximum reaction rate between the oxygen, water, and sulfuritic compounds. The total acid output is limited only by the quantity of water available. As flows increase, this reaction rate

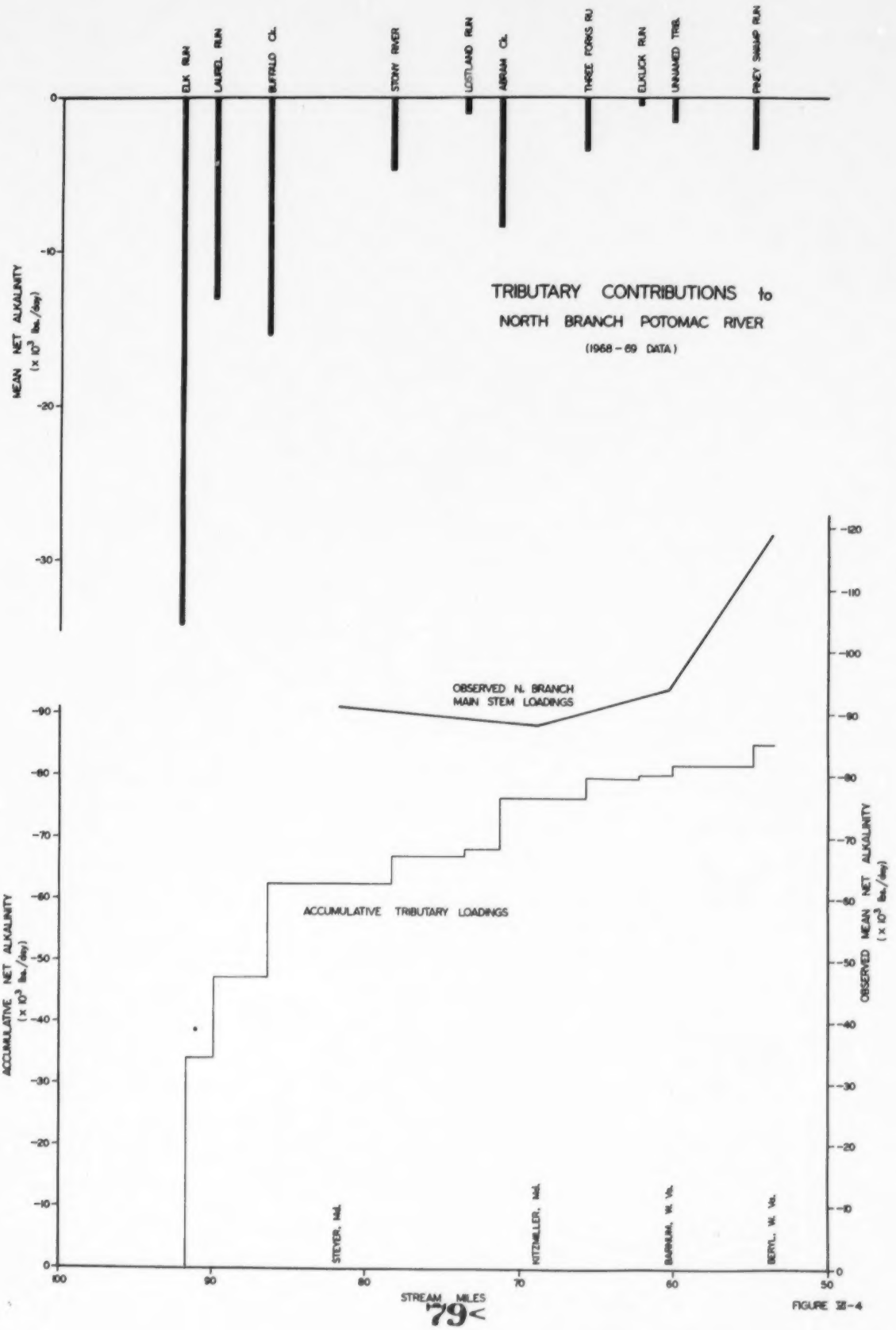

ELK RUN
LAUREL RUN
BUFFALO CR.
STONY RIVER
LOSTLAND RUN
ABRAM CR.
THREE FORKS RU
ELKLICK RUN
UNNAMED TRIB.
PINEY SWAMP RUN
MEAN NET ALKALINITY
(x 10³ lbs./day)
TRIBUTARY CONTRIBUTIONS to
NORTH BRANCH POTOMAC RIVER
(1968 - 69 DATA)
OBSERVED N. BRANCH
MAIN STEM LOADINGS
ACCUMULATIVE TRIBUTARY LOADINGS
ACCUMULATIVE NET ALKALINITY
(x 10³ lbs./day)
OBSERVED MEAN NET ALKALINITY
(x 10³ lbs./day)
STEYER, MD.
KITZMILLER, MD.
BARNUM, W. Va.
BERYL, W. Va.
STREAM MILES

FIGURE 22-4

decreases due to an overabundance of water compared to the availability of the other constituents. During exceptionally high flow periods, a point of diminishing returns occurs. The production of acid approaches a maximum with the load becoming increasingly dependent upon flow. This dependency can readily be observed by examining the following equation which was used to derive acid loadings:

$$L = Ac \times Q \times 5.4$$

Where:

L = acid load (lbs/day)

A_c = acid concentration (mg/l)

Q = flow (cfs), and

5.4 = conversion factor

In the calculations, the streamflow (Q) is incorporated in the load computation, and therefore an automatic bias is injected into any L versus Q analysis.

Figures VI-5 and VI-6 present least-squares regression lines in the form of Eq VI-2 which describe the acid load - streamflow relationship at two of the sampling stations investigated. Table VI-5 presents the equations and correlation coefficients for every regression analysis having a minimum of 12 observations. The regression equations shown in Table VI-5 indicate a relatively small variation in the slope (b) term despite gross changes in other factors. This implies that changes in the rate of acid production, due to increasing flow, are practically uniform in all of the major tributary streams and consequently in the North Branch Potomac River itself.

ACID LOAD - STREAM FLOW RELATIONSHIP

BUFFALO CREEK

BAYARD, W. Va.

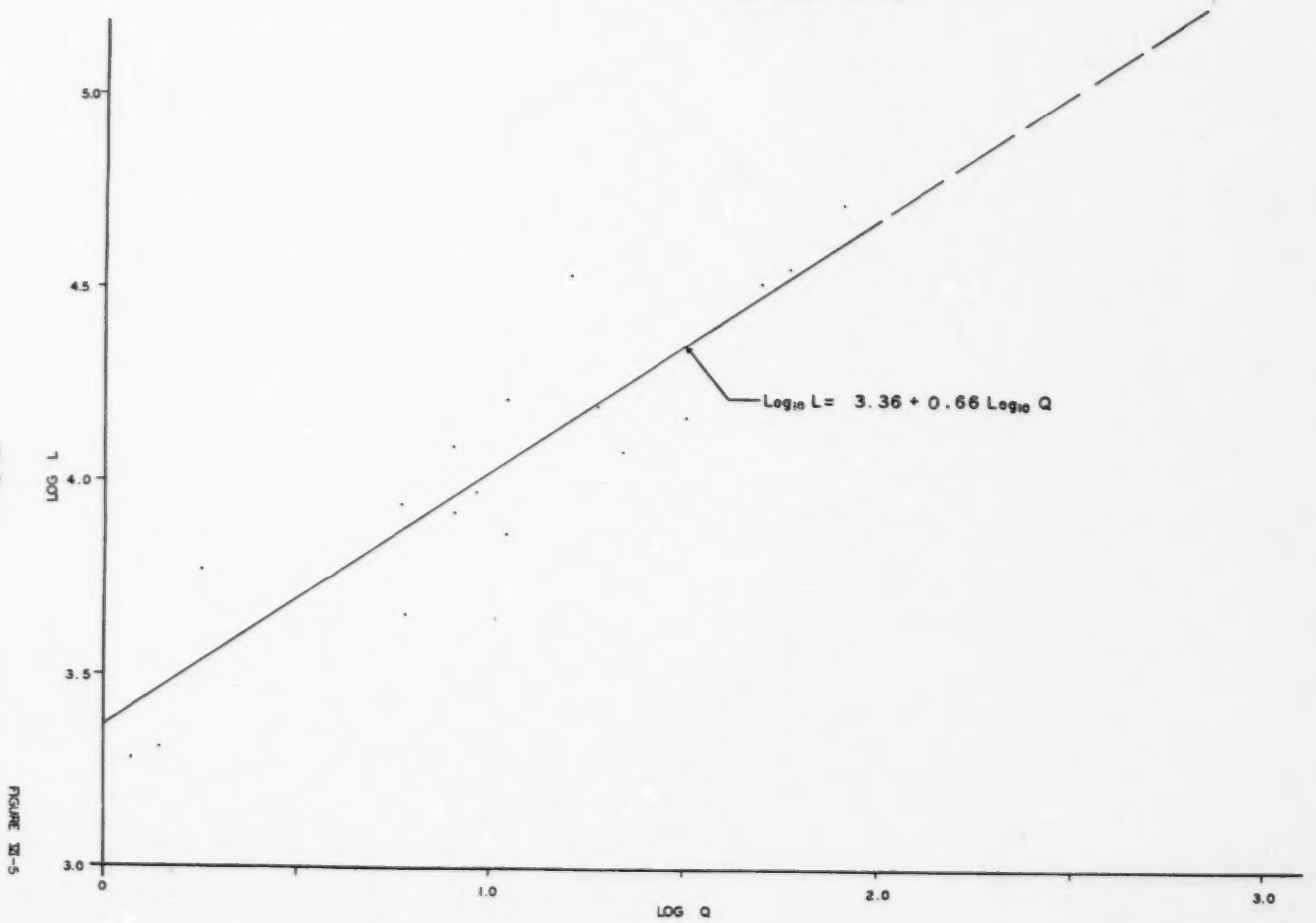
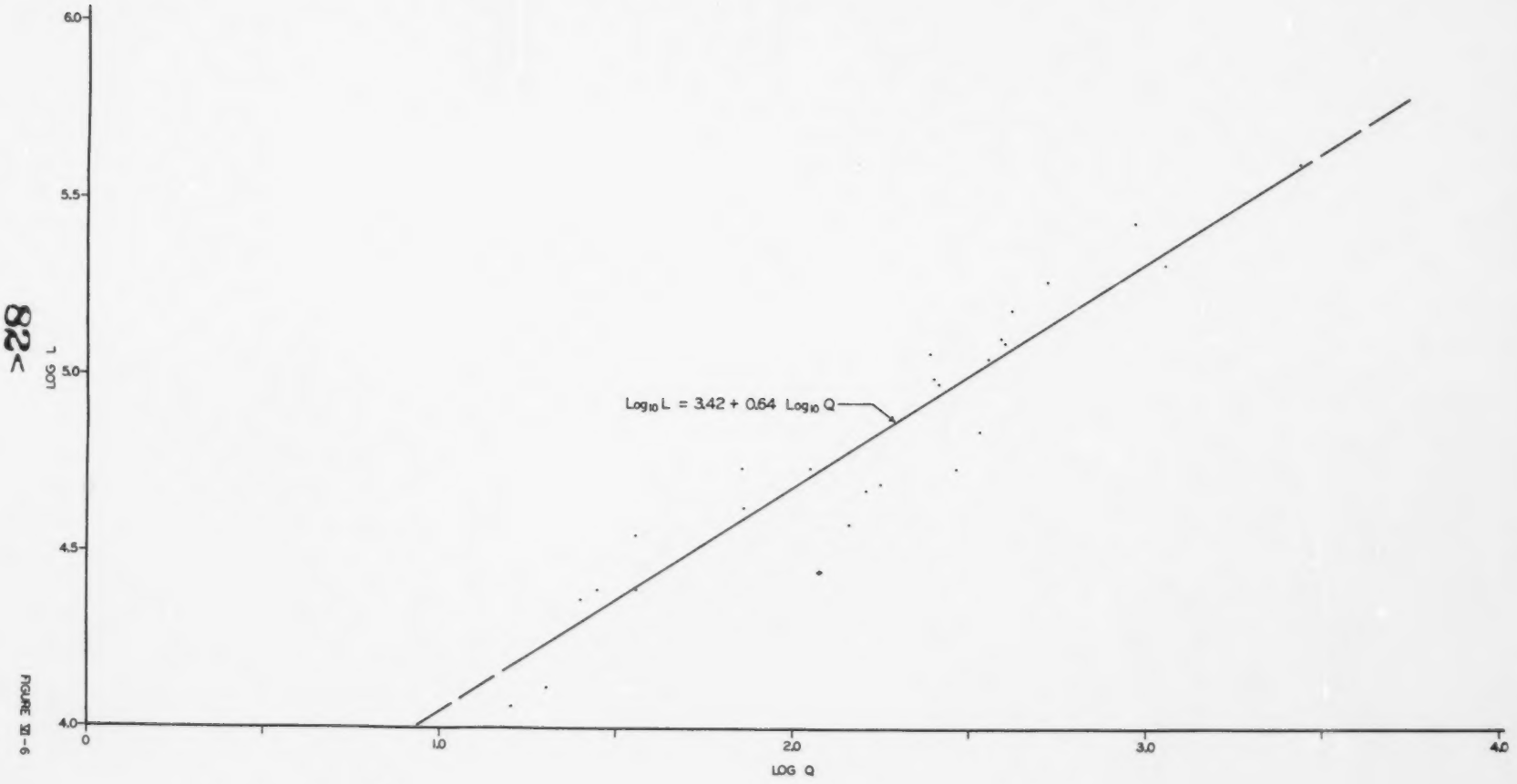


FIGURE XII-5

ACID LOAD - STREAM FLOW RELATIONSHIP

NORTH BRANCH POTOMAC RIVER

BARNUM, W. Va.



82<

FIGURE III-6

TABLE VI-5

REGRESSION STUDY RESULTS

	Sampling Station	Regression Equation	Correlation Coefficient	A Degrees of Freedom
1.	Elk Run at Henry Siding	$L = 19{,}500\ Q^{.67}$	0.85**	16
2.	Buffalo Creek at Bayard	$L = 2{,}300\ Q^{.66}$	0.92	16
3.	N. Br. Potomac at Steyer	$L = 5{,}200\ Q^{.57}$	0.91	29
4.	Abram Creek at Oakmont	$L = 810\ Q^{.58}$	0.87	29
5.	N. Br. Potomac at Kitzmiller	$L = 3{,}150\ Q^{.58}$	0.92	29
6.	Three Forks Run at East Vindex	$L = 1{,}900\ Q^{.40}$	0.92	31
7.	N. Br. Potomac at Barnum	$L = 2{,}590\ Q^{.64}$	0.96	24
8.	Piney Swamp Run at Hampshire	$L = 2{,}650\ Q^{.49}$	0.82	11
9.	N. Br. Potomac at Beryl	$L = 2{,}580\ Q^{.64}$	0.92	29

** Significance at the 1% level

A D.F. = Number of observations (N) - 2

CHAPTER VII

EFFECTS OF MINE DRAINAGE POLLUTION

A. WATER SUPPLY

1. Water Used

The Luke, Westernport, Keyser area currently obtains its water from alkaline tributaries of the North Branch Potomac River (Savage River and New Creek) and from ground water. The West Virginia Pulp and Paper Company utilizes the North Branch Potomac for its entire water supply. The Celanese Corporation withdraws approximately 58 mgd from the North Branch near Amcelle and obtains the remaining 3 mgd from the City of Cumberland. The water supply source for the City of Cumberland is Evitts Creek which has a dependable yield of 18 mgd.

The principal water users and the projected water supply demands are presented in Table VII-1. According to Table VII-1, the municipal and industrial water supply requirements, excluding cooling water, are projected to increase drastically over the next 50 years. This increased demand will necessitate further usage of the North Branch Potomac since the Potomac is probably the only stream in the area capable of providing sufficient flows to meet future water supply needs.

TABLE VII-1

PROJECTED WATER SUPPLY DEMANDS

Water User	Present (mgd)	1980 (mgd)	2000 (mgd)	2020 (mgd)
Luke, Westernport, Keyser	1.5	3.25	5.50	6.9
West Virginia Pulp and Paper Company	72.0*	28.0***	40.0***	56.0***
Celanese Fibers Company	61.0*	15.0***	21.0***	25.0***
Cumberland	5.55**	7.70**	12.75**	17.20**

* Includes Cooling Water
** Municipal Use Only
*** Excludes Cooling Water

2. Effects of Mine Drainage

Streams impregnated with constituents normally found in mine drainage; i.e., sulfuric acid, iron, manganese, aluminum, calcium, and magnesium salts are undesirable sources of municipal, industrial, and agricultural water supply. Modern and adequately designed water treatment plants are capable of removing these constituents but at considerable cost.

In water treatment plants, high acidity and low pH may adversely affect chemical coagulation, softening, and corrosion control with the latter being the major problem of most industrial users. Both iron and manganese create serious problems in public water supplies.

These problems are caused by the precipitation of iron and manganese salts which are objectionable aesthetically and which stain and corrode plumbing fixtures and laundry. Iron also supports the growth of filamentous iron bacteria which may obstruct the flow of water in distribution lines. The U. S. Public Health Service recommends a maximum iron and manganese concentration in public water supplies of 0.3 mg/l and 0.05 mg/l, respectively.

Calcium and magnesium salts produce permanent hardness in water. Hardness is objectionable in both public supplies and especially in industrial boiler feed water.

The North Branch at Luke, which is used as an industrial water supply by the West Virginia Pulp and Paper Company, is characterized by low pH, high acidity, and high iron. For the months of June, July, and August, 1969, the total iron in the incoming water varied from a minimum of 1.0 mg/l to a maximum of 7.0 mg/l with an average of 2.3 mg/l. To meet their current process water requirements for "fine paper" production, the incoming water is treated to remove the acidity, turbidity, managanese, and iron.

To provide for existing and future water supply needs, a 50 percent increase in the demineralization capacity by the West Virginia Pulp and Paper Company is planned. The cost of this expansion, which is required by the poor quality of the incoming water, is projected to $300,000. The increase in water supply treatment cost due to the mine drainage constituents in the incoming water is estimated to be about 50 percent above normal renovation cost.

At the West Virginia Pulp and Paper Company, lime is added to incoming cooling water to protect the condensers against corrosion. In recent years, corrosion of the cooling water condenser at the Celanese Fibers Company has been observed.

Population centers, such as Westernport, Keyser, and particularly Cumberland, are situated along the North Branch Potomac River but cannot readily utilize it as a water supply source because of mine drainage and industrial waste pollution. The acidity from upstream mine drainage occasionally constitutes a major problem in the vicinity of Cumberland, especially biologically (See Section VII-B). A reduction in alkalinity at the West Virginia Pulp and Paper Company discharge, due to process change, would undoubtedly alter the acid-alkaline balance of the North Branch Potomac for a considerable distance and thereby lessen its potential as a water supply source.

B. ECOLOGY

There are approximately 150 miles of streams in the North Branch Potomac basin which are currently devoid of fish life because of mine drainage. Many of the tributary streams and portions of the North Branch Potomac itself could otherwise support a cold water fishery.

Biological (benthic) sampling was conducted throughout the North Branch basin during the summer and fall of 1966. Generally, the tributary streams receiving mine drainage were found to be "biological deserts." The North Branch Potomac upstream from Kitzmiller also contained practically no form of biological organisms. Downstream

from Kitzmiller, the biological sampling revealed only sparse populations of acid tolerant forms.

The North Branch Potomac does not appear to recover biologically until it reaches Oldtown, approximately 10 miles downstream from Cumberland. The biological depression below Luke can also be attributed in part to large quantities of industrial waste being discharged into the reach between Westernport and Cumberland.

One of the most critical stresses which mine drainage exerts on the "in-stream" environment is its extreme toxicity to all forms of aquatic life. Only a scant number of aquatic forms, both macroscopic and microscopic, can exist in an environment strongly influenced by mine drainage. Not only does mine drainage cause this effect near the point of origin, but without dilution, it may destroy biological activity for many miles downstream. As indicated previously, much of the upper North Branch is a "biological desert."

The acidity in mine drainage produces low pH values in the streams and the metallic constituents produce toxic precipitates. Both of these are capable of sterilizing a stream. It is generally agreed that an aquatic environment having a pH less than 6.0 cannot support a well balanced aquatic population (pH values in the North Branch Potomac were as low as 2.1). The basic ferric sulfate, known as "yellow boy," presently covers many miles of stream beds. This precipitate chokes all benthic life thus destroying the food chain for the higher aquatic forms. When mine drainage depresses

the microscopic population in a stream, its ability to stabilize sewage or organic industrial waste biochemically is also impaired.

C. BLOOMINGTON RESERVOIR

The U. S. Army Corps of Engineers' Bloomington Reservoir Project, which is in the final stages of pre-construction planning, will be located on the North Branch Potomac eight miles upstream from Bloomington near Barnum, West Virginia. The Bloomington Reservoir is designed as a multiple purpose project with storage provided for water supply, water quality control, flood control, and recreation. At the conservation pool level, the dam will impound 94,700 acre-feet of water.

Sampling data collected from the North Branch at Barnum indicated that the proposed reservoir will impound water containing large quantities of mine drainage. As shown in Figure V-11, the pH levels of the incoming water can be as low as 2.6 with acidity concentrations as high as 180 mg/l during the critical late summer and early fall. Even during high flow periods, pH levels under 4.0 and acid concentrations exceeding 30 mg/l can be anticipated. Projecting the condition from Barnum, acid loadings into the impoundment ranging from 12,000 to 395,000 lbs/day, with an average of 94,000 lbs/day, can be expected. Total iron concentrations will range from 1.0-5.0 mg/l.

Since the proposed reservoir will impound a large volume of mine drainage, it becomes necessary: (1) to predict what chemical

reactions if any will occur in the reservoir, (2) to determine what subsequent changes in water quality will result from these reactions, and (3) to evaluate the effects of the resultant water quality on the intended uses of the reservoir.

Wilkes College in Wilkes-Barre, Pennsylvania under contract with FWPCA (CB-SRBP) [13] has undertaken a study of the kinetics of mine drainage impoundments. Among the purposes of this study was the determination of the rate of iron oxidation and hence, the rate of free acid production in mine water impoundments. Although the reservoirs investigated in the Wilkes study were located in the anthracite coal fields of northeastern Pennsylvania, a generalization of the findings appears to be applicable to the Bloomington Project. These findings are outlined as follows:

1. In an impoundment which has a pH between 3 and 6 and an initial iron concentration in excess of 10 mg/l, the rate of ferrous iron oxidation appears to be approximately 3 mg/l per day. Below a concentration of 10 mg/l ferrous iron, a lesser oxidation rate was observed. Neither surface area, volume, nor temperature had a noticeable effect on the results. Once iron is oxidized, it is removed from solution as a precipitated hydrous iron oxide.

2. A significant decrease in pH accompanied the oxidation of iron.

3. There is little change in acidity concentration as a result of long-term impoundment of mine drainage.

4. No change was found in concentrations of manganese, calcium, magnesium, or hardness as a result of long-term impoundment. Small amounts of sulfate were found to precipitate along with iron but the amount was unpredictable. From the above results, it can be concluded that the water quality will either remain essentially unchanged or will deteriorate in the impoundment with the exception of ferrous iron concentrations.

If the quality in the impoundment is as anticipated, the intended purposes of recreation and flow regulation for water quality control will not be developed to its full potential unless a mine drainage control program is initiated. The excessive mine drainage content of Bloomington Reservoir will also lessen the utility of the impounded water for water supply unless complete treatment, including neutralization, is anticipated similar to that currently being provided by the West Virginia Pulp and Paper Company for their processed water. Based upon a comparison of the average acid load released from the Bloomington Reservoir and the little alkalinity reserve in Savage I, utilizing the flow releases from this impoundment for acid neutralization in the North Branch Potomac below Savage River does not appear to have significant potential.

Using (1) an average acidity concentration of 100 mg/l in the impoundment, (2) the minimum regulated base flow from the proposed reservoir of 205 cfs, and (3) pH-acidity relationship as developed in Chapter IV-C, the cost of neutralizing the acid to maintain a pH within the limits set forth by stream standards in Bloomington was determined as follows:

(i) Acid loading in lbs/month

(100 + 5) mg/l x 205 cfs x 30 days x 5.4 = 3,530,000 lbs/month

where

(100 + 5) = the net alkalinity required to raise the pH to 6.0

(ii) Lime requirements to neutralize the acid load

$$\frac{56 \text{ A. W. Ca O}}{100 \text{ A. W. } CaCO_3} \times 3{,}530{,}000 = 1{,}980{,}000 \text{ lbs/month}$$

where

A. W. = Atomic weight of the compounds
CaO = Calcium oxide or lime
$CaCO_3$ = Calcium carbonate

(iii) Cost of Neutralization

1,980,000 x $.01/lb = $19,800/month

where

the cost of lime = $20/ton or $.01/lb

On an annual basis the cost of acid neutralization to maintain a pH of 6.0 would be $238,000/year.

Another important consideration is the possibility of any abandoned mines in the immediate vicinity of the reservoir being subject to recurrent filling and emptying operations thereby producing acid which otherwise would not have been generated. The generation of any additional acidity in the North Branch above the Bloomington Reservoir would aggravate the existing water quality problem and further detract from the usefulness of the proposed Bloomington Project.

To aid in minimizing hydraulic surges which contain low pH waters, the Bloomington Reservoir could provide a direct benefit in water quality management. However, the magnitude of this benefit would be contingent on the reserve storage in the reservoir pool. For example, the fish kill which occurred in August 1969, might have been averted had adequate storage been available to impound the acid "slug" responsible for this fish kill.

CHAPTER VIII

CONTROL METHODS AND COSTS

A. GENERAL CONSIDERATIONS

There are various methods available to control or eliminate mine drainage. The abatement methods as discussed in this report can generally be categorized as follows:

1. Prevention
2. Treatment
3. Dilution

Measures which can be instituted to prevent the formation of mine drainage at its source include but are not limited to: (a) inundation of deep mine workings, (b) reconstruction of stream channels, (c) construction of surface water diversion ditches, (d) restoration and filling of strip mines, (e) excavation and restoration of subsidence areas, and (f) construction of impermeable seals on or below the ground surface. Preventive measures can be designed to reduce the volume of mine drainage and acidity loadings by 10 to 100 percent.

Chemical treatment of mine drainage has received considerable attention recently, probably because this method can produce immediate results and can be positively controlled. A typical mine drainage treatment plant should be capable of providing neutralization of the acid, oxidation of the iron compounds, and settlement of precipitates. More exotic methods of treatment such as electrodialysis, ion exchange,

reverse osmosis, etc. are being investigated but early indications are that all would be too high in cost on a large scale project.

Another important consideration is the collection and impoundment of mine drainage prior to treatment. In areas where extensive disturbance has occurred, the cost of collection may represent a significant portion of the total expenditure. Since over 50 percent of acid loadings is from 20 square miles, the collection problem may be simplified.

Dilution and neutralization of the acid content by either natural or chemical means is also a method of reducing the "in-stream" effects of mine drainage pollution. If the quantity and quality of the natural dilution flow from non-mining areas is sufficient, it will neutralize the mine drainage acidity and also increase the pH to acceptable levels. In the North Branch Potomac basin, the tributary streams receiving most of the mine drainage have a minimum of natural dilution flow of good water quality. Furthermore, most of the acid streams, excepting Stony River and Savage River, have no reservoirs or other provisions for flow regulation.

Detailed engineering studies for the purpose of establishing a mine drainage pollution abatement program for a specific area are very limited. Gannett, Fleming, Corddry, and Carpenter, Inc., (GFCC), Harrisburg, Pennsylvania, under contract with the Federal Water Pollution Control Administration, conducted small scale studies of this type in five selected areas of the Susquehanna River basin.

The data obtained from these studies were subsequently used to develop cost estimates for larger and more complex watersheds within the Susquehanna basin.

The findings of the GFCC study indicated a large variation in abatement costs depending upon the schemes investigated. The abatement schemes or plans were developed on the basis of compliance with present Pennsylvania Sanitary Water Board discharge limitations. These limitations are as follows:

1. pH not less than 6 nor greater than 9
2. Iron concentration not in excess of 7 mg/l
3. No acid

Generally, a combination of preventive measures and treatment proved to be the most economical method of achieving the desired water quality over the long term. Mine drainage reduction (volume and acidity) attributable to preventive measures alone was normally about 20 percent. The remaining volume and acid load has to be provided for in the design of the collection system and treatment facility.

B. COSTS

In order to predict the costs of mine drainage control in the North Branch Potomac basin, an analysis was made of the feasibility and effectiveness of various abatement schemes investigated in the Susquehanna basin [15]. These schemes, which consist of the preventive measures discussed in the preceding section, and treatment

appear to be applicable in the Potomac basin since there are many similarities in the historical mining trends and current mining activity in West Virginia, Maryland, and Pennsylvania. The only significant difference is that active mining in the Potomac basin is more predominant and therefore contributes a larger percentage of the acid load than it does in the Susquehanna.

The primary problem associated with predicting mine drainage control costs in this study originates from lack of data pertaining to individual acid discharges. The water quality data collected during the North Branch Potomac survey was "in-stream" sampling data with no monitoring of specific discharges.

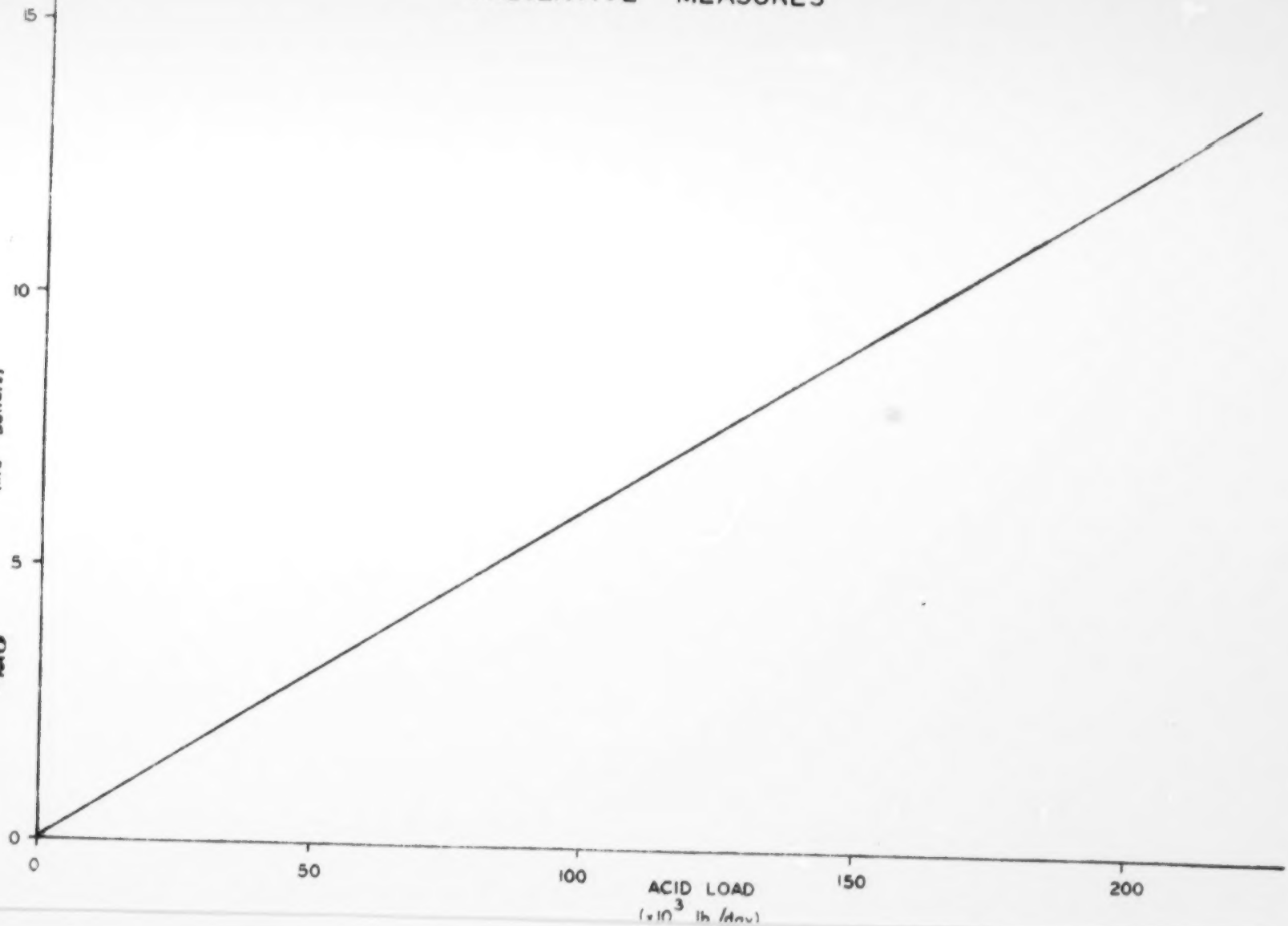
Since acidity data are more indicative of mine drainage and are more available than most other data, and since acidity loadings were used to a certain extent for cost analysis in the Susquehanna basin, the costs of mine drainage control for this study were developed as a function of total acidity loadings. The following relationships, presented in Figures VIII-1, VIII-2, and VIII-3, were used in computing the cost of mine drainage control as developed from the Susquehanna study:

1. First Cost-Preventive Measures vs Acidity
2. First Cost-Collection vs Acidity, and
3. First Cost-Treatment vs Acidity

The costs, which would be considered preliminary in nature, are additive. That is, for a given loading, the cost of mine

MINE DRAINAGE ABATEMENT COSTS

PREVENTIVE MEASURES



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I - FIGURE XIII - 1

NORTH BRANCH, BERYL, W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 26	31368.0000	1940.0000	3.2000	0.0 B	4.0000	0.0	23.0000	240055.4375	0.0 B	0.0 B
CFS 26	32768.0000	1140.0000	3.0000	0.0 B	11.0000	0.0	29.0000	177862.6250	16.0000	98131.1250
CFS 26	41048.0000	432.0000	2.6000	0.0 B	12.0000	0.0	34.0000	79021.3750	85.0000	197553.5000
CFS 26	50168.0000	151.0000	3.4000	0.0 B	14.0000	0.0	60.0000	48742.7773	200.0000	162475.8750
CFS 26	51368.0000	797.0000	0.0 B	0.0 B	14.0000	0.0	19.0000	81469.2500	66.0000	291574.1250
CFS 26	52768.0000	3150.0000	4.0000	0.0 B	14.0000	0.0	26.0000	440621.8750	61.0000	**********
CFS 26	61268.0000	298.0000	3.4000	0.0 B	24.0000	0.0	77.0000	123449.4375	168.0000	269344.2500
CFS 26	62668.0000	123.0000	3.3000	0.0 B	24.0000	0.0	92.0000	60880.0547	200.0000	132347.9375
CFS 26	71068.0000	30.0000	3.2000	0.0 B	27.0000	0.0	135.0000	21788.7922	330.0000	53261.9844
CFS 26	72468.0000	21.0000	3.1000	0.0 B	21.0000	0.0	157.0000	17737.8555	279.0000	31521.4141
CFS 26	80768.0000	76.0000	3.2000	0.0 B	26.0000	0.0	154.0000	62567.5000	211.0000	85273.6250
CFS 26	82868.0000	25.0000	3.4000	0.0 B	18.0000	0.0	109.0000	14660.4961	34.0000	4572.9961
CFS 26	91168.0000	61.0000	2.8000	0.0 B	0.0 B	0.0	222.0000	72855.9375	358.0000	130615.5625
CFS 26	92568.0000	7.0000	2.7000	0.0 B	20.0000	0.0	125.0000	4707.4961	450.0000	16946.9922
CFS 26	100468.0000	39.0000	0.0 B	0.0 B	12.0000	0.0	200.0000	43852.3711	846.0000	177507.6250
CFS 26	102368.0000	32.0000	2.8000	0.0 B	13.0000	0.0	164.0000	28234.2344	323.0000	55607.6680
CFS 26	110668.0000	33.0000	3.0000	0.0 B	12.0000	0.0	138.0000	24500.5117	440.0000	78117.5625
CFS 26	112068.0000	554.0000	3.1000	248.0000	2.0000	0.0	62.0000	184792.1875	120.0000	357662.3125
CFS 26	120468.0000	403.0000	2.8000	390.0000	6.0000	0.0	70.0000	151769.7500	126.0000	273185.5625
CFS 26	121868.0000	278.0000	3.6000	240.0000	0.0	0.0	60.0000	86738.3750	104.0000	155546.5000
CFS 26	130968.0000	0.0 B	3.0500	185.0000	0.0	0.0	103.5200	0.0 B	267.0000	0.0 B
CFS 26	132268.0000	0.0 B	3.0500	230.0000	1.0000	0.0	50.2400	0.0 B	61.0000	0.0 B
CFS 26	23568.0000	930.0000	3.3000	185.0000	1.0000	0.0	125.1200	626023.1875	74.0000	370251.4375
CFS 26	22668.0000	227.0000	3.0000	365.0000	1.0000	0.0	63.5600	77623.2500	205.0000	250358.2500
CFS 26	31268.0000	150.0000	3.3000	0.0 B	0.5000	0.0	77.7000	62703.6750	151.0000	154136.9375
CFS 26	40268.0000	1154.0000	3.5000	0.0 B	7.0000	0.0	44.0000	273174.6875	76.0000	471847.1875
CFS 26	41668.0000	430.0000	2.8000	360.0000	12.0000	0.0	56.7000	131169.6875	135.0000	312308.8750
CFS 26	50768.0000	212.0000	3.3000	0.0 B	18.0000	0.0	52.5000	59879.3867	112.1000	127856.6875
CFS 26	51468.0000	392.0000	3.1500	320.0000	12.0000	0.0	44.9000	94692.2500	219.1000	462073.0000
CFS 26	52148.0000	402.0000	0.0 B	280.0000	17.3000	0.0	36.0000	77959.3125	101.5000	219520.0625
CFS 26	52768.0000	177.0000	3.1000	260.0000	16.5000	0.0	74.0000	70467.1875	40.7000	38756.9687

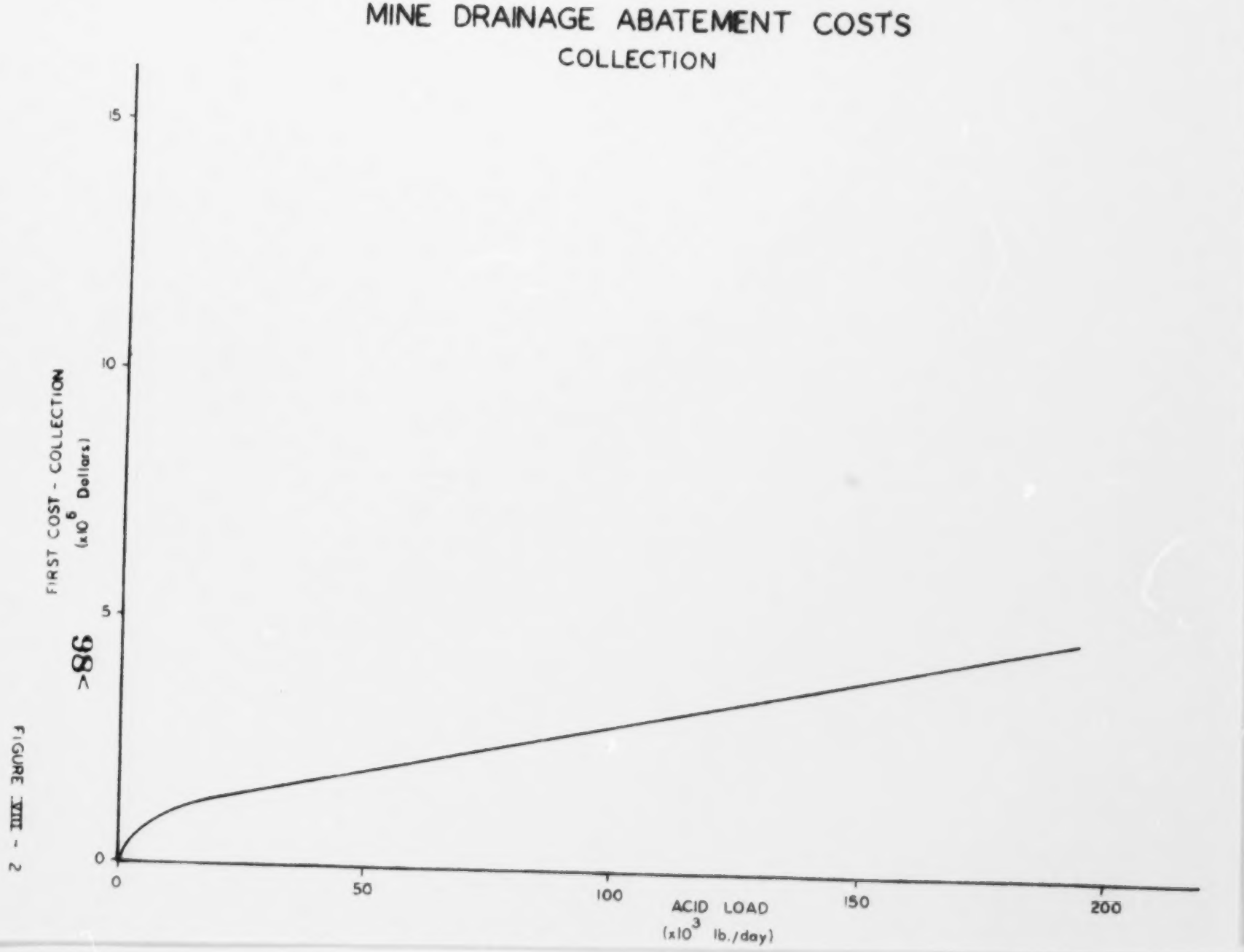

FIGURE XIII - 2

MINE DRAINAGE ABATEMENT COSTS

TREATMENT

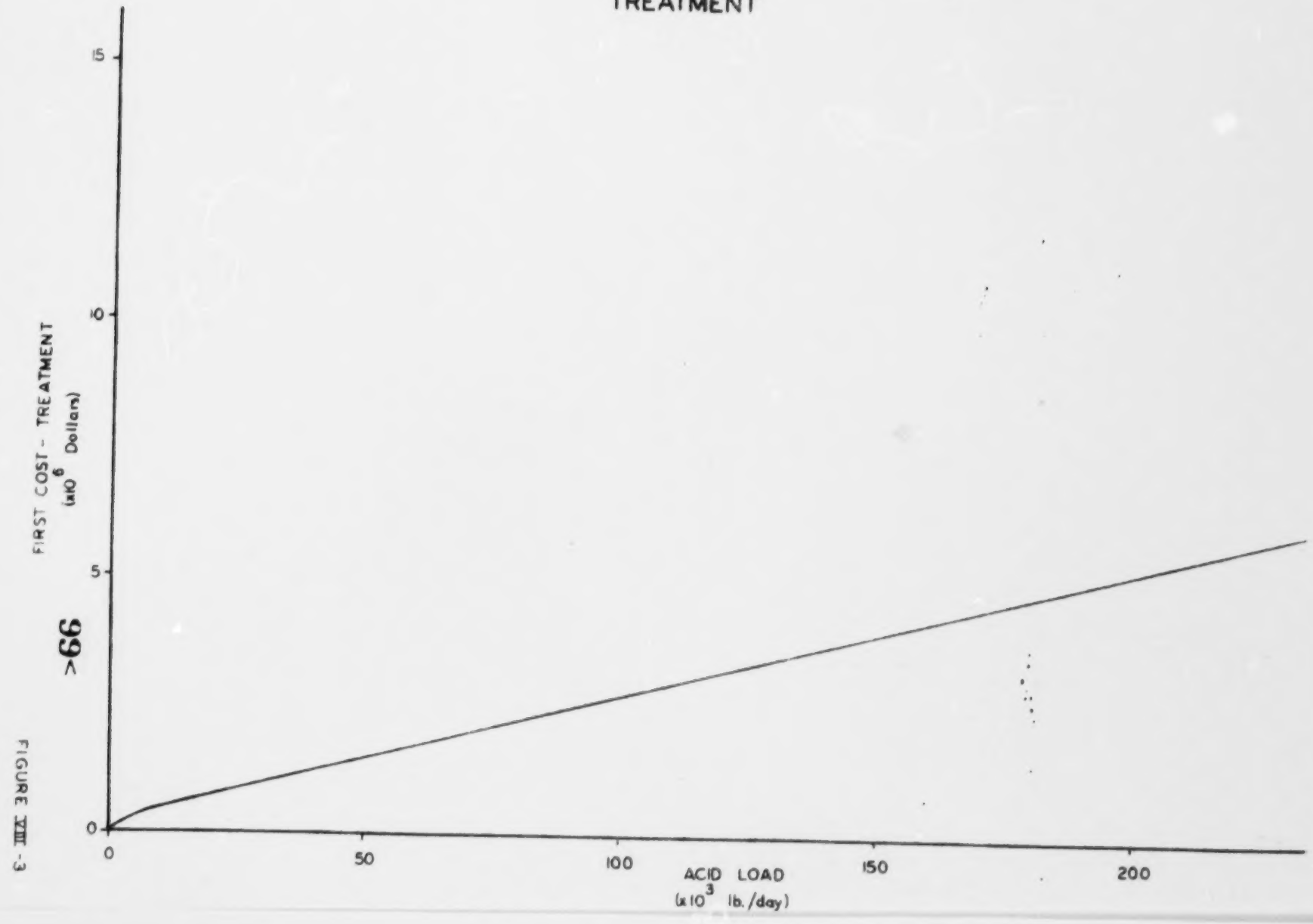

FIGURE XIII-3

drainage control could consist of all three cost components: prevention, collection, and treatment.

In calculating the abatement costs, seven watersheds were included (Table VIII-1). These watersheds represent approximately 70 percent of the total acid load in the North Branch Potomac River at Beryl. The maximum acidity loading for each watershed was used as the basis of computing the design criteria.

The operation and maintenance annual costs (O & M) were determined as a percent of the construction cost. The figure used for prevention was 2 percent, collection 5 percent, and treatment 30 percent. The total annual cost, as reported in Table VIII-1, consists of O & M plus first cost amortized at 5 percent interest rate. An amortization period of 30 years was used for collection and treatment with a 100 year period for preventive measures.

Table VIII-1 presents observed and design loadings along with construction costs and annual costs for preventive measures, collection systems and treatment facilities in seven tributary watersheds. The costs in Table VIII-1 are preliminary and should be interpreted only as an order of magnitude of the expense necessary to control mine drainage pollution in the Potomac basin.

For the above conditions, the estimated construction cost for abatement of mine drainage in the seven watersheds is $32,450,000. When operation and maintenance are included, the annual costs were estimated to be about $5 million/year.

Table VIII-1

PRELIMINARY MINE DRAINAGE ABATEMENT COSTS

North Branch Potomac Basin

	Watershed	Mean Acidity (observed) lb/day	Design Acidity lb/day	Preventive Measures First Cost $x10^6	Preventive Measures O&M* $x10^6	Preventive Measures Annual $x10^6	Collection & Imp. First Cost $x10^6	Collection & Imp. O&M $x10^6	Collection & Imp. Annual $x10^6	Treatment First Cost $x10^6	Treatment O&M $x10^6	Treatment Annual $x10^6	Total First $x10^6	Total O&M $x10^6	Total Annual $x10^6
1.	Elk Run	35,000	100,000	6.15	0.15	0.31	.00**	.00	.00	2.70	0.81	0.18	8.85	0.93	1.42
2.	Laurel Run	13,000	40,000	2.45	0.05	0.12	1.70	0.08	0.11	1.20	0.36	0.08	5.35	0.49	0.80
3.	Buffalo Creek	16,000	50,000	3.10	0.06	0.16	1.90	0.10	0.12	1.50	0.45	0.10	6.50	0.61	0.99
4.	Stony River	4,500	20,000	1.20	0.02	0.06	1.30	0.06	0.08	0.70	0.21	0.04	3.20	0.29	0.47
5.	Abram Creek	9,000	30,000	1.85	0.04	0.09	1.50	0.08	0.10	1.00	0.30	0.06	4.35	0.42	0.67
6.	Three Fork Run	3,300	10,000	0.06	0.01	0.03	1.00	0.05	0.06	0.50	0.15	0.03	2.10	0.21	0.33
7.	Piney Swamp Run	3,200	10,000	0.60	0.01	0.03	1.00	0.05	0.06	0.50	0.15	0.03	2.10	0.21	0.33
													32.45		5.01

* O&M = yearly operation and maintenance costs

** Since most of the mine drainage is mainly from one active operation, no massive collection system would be required.

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NORTH BRANCH POTOMAC RIVER 1968 - 1969 MINE DRAINAGE STUDY
ANALYTICAL RESULTS AT SAMPLING STATIONS

ELK RUN, HENRY SIDING, W.VA.

SAMPLE		DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS	2	31468.0000	5.8000	2.0000	0.0 B	4.0000	0.0	2000.0000	62407.9570	300.00008	0.0 B
CFS	2	32768.0000	3.1000	1.7000	0.0 B	12.0000	0.0	1950.0000	32522.0859	308.0000	5136.8203
CFS	2	41068.0000	2.1000	1.9000	0.0 B	12.0000	0.0	2173.0000	24550.5391	2950.0000	33329.0820
CFS	2	50168.0000	1.0000	5.8000	0.0 B	14.0000	0.0	1960.0000	10544.7969	7080.0000	38090.3906
CFS	2	51568.0000	2.2000	1.90008	0.0 B	22.0000	0.0	1440.0000	17043.8320	2320.0000	23308.7109
CFS	2	52768.0000	4.0000	2.5000	0.0 B	12.0000	0.0	4580.0000	98561.5000	4760.0000	102435.1250
CFS	2	62568.0000	1.5000	3.0000	0.0 B	20.0000	0.0	5800.0000	46805.9922	2440.0000	19690.7969
CFS	2	72468.0000	0.3000	2.7000	0.0 B	27.0000	0.0	5640.0000	9102.3531	4340.0000	8053.8555
CFS	2	82968.0000	0.6000	2.8000	0.0 B	23.0000	0.0	5910.0000	19077.4687	8160.0000	26340.4687
CFS	2	92568.0000	0.2000	2.3000	0.0 B	19.0000	0.0	6200.0000	6671.1953	14310.0000	15387.5469
CFS	2	102368.0000	0.1000	2.4000	0.0 B	16.0000	0.0	8796.0000	4732.2422	7250.0000	3900.4976
CFS	2	112068.0000	2.8200	2.2000	2200.0000	2.0000	0.0	3760.0000	132903.1250	3880.0000	58865.7851
CFS	2	121968.0000	2.5000	2.6000	0.0	4.0000	0.0	2560.0000	34431.9922	3560.0000	48150.9922
CFS	2	12269.0000	3.2000	2.4000	1850.0000	4.5000	0.0	2639.7998	45446.7617	3742.0000	67865.3750
CFS	2	22669.0000	1.4000	2.6000	2020.0000	1.0000	0.0	2764.7998	20824.4609	8440.0000	63546.6484
CFS	2	40369.0000	4.9000	2.3500	0.0 B	8.0000	0.0	1375.0000	36247.7266	1344.0000	43729.5977
CFS	2	52169.0000	1.2000	2.40008	3250.0000	25.0000	0.0	3228.7000	20844.4766	1344.0000	8709.1367
CFS	2	52769.0000	1.1500	3.1000	0.0 B	23.0000	0.0	3207.2998	19843.5508	6363.0000	39367.8555
CFS	2	52769.0000	0.0 B	2.7000	3000.0000	17.0000	0.0	0.0 B	0.0 B	0.0 B	0.0 B

LEGEND:

SAMPLE	Station Number
DATE	Month-Day-Year
FLOW	Cubic Feet Per Second
PH	pH
COND	Conductivity in Micromhos
TEMP	Temperature in Degrees Centigrade
ALK T	Total Alkalinity in mg/l
AC TH	Total Hot Acidity in mg/l
AC TH(Q)	Acidity Loading in lbs/day
SO4	Sulfates in mg/l
SO4(Q)	Sulfate Loading in lbs/day
B	No Observation Made
N	Below Limit of Equipment Sensitivity

LAUREL RUN, DOBBIN RD.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
MDNR 4	53168.0000	34.0000	3.0000	0.0 B	0.0 B	0.0	60.0000	10975.1953	180.0000	32925.5937
MDNR 4	61468.0000	16.0000	2.8000	0.0 B	0.0 B	0.0	262.0000	22552.9531	260.0000	22380.7930
CFS 4	62668.0000	7.5000	3.1000	0.0 B	22.0000	0.0	583.0000	23524.0430	542.0000	21869.6914
MDNR 4	62868.0000	5.8000	2.8000	0.0 B	0.0 B	0.0	244.0000	7613.7695	800.0000	24963.1836
MDNR 4	71568.0000	3.8000	2.9000	0.0 B	0.0 B	0.0	312.0000	6378.5195	115.0000	2351.0581
CFS 4	72468.0000	3.8000	2.4000	0.0 B	26.0000	0.0	368.0000	7523.3828	800.0000	16477.8516

BUFFALO CREEK, BAYARD, W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 5	31468.0000	59.0000	3.0000	0.0 B	3.0000	0.0	112.0000	35551.0312	0.0 B	0.0 B
CFS 5	32768.0000	32.0000	2.4000	0.0 B	11.0000	0.0	85.0000	14633.5977	50.0000	8607.9561
CFS 5	41068.0000	11.0000	2.4000	0.0 B	12.0000	0.0	124.0000	7338.3164	210.0000	12427.7930
CFS 5	50168.0000	6.1000	5.6000	0.0 B	18.0000	0.0	138.0000	4528.8789	277.0000	9090.5781
CFS 5	51568.0000	22.0000	0.0 B	0.0 B	19.0000	0.0	101.0000	11954.3555	152.0000	17990.7148
CFS 5	52768.0000	101.0000	3.6000	0.0 B	10.0000	0.0	96.0000	52164.4687	118.0000	64118.8242
CFS 5	62668.0000	5.9000	3.4000	0.0 B	10.0000	0.0	275.0000	8729.0469	375.0000	11903.2422
CFS 5	72468.0000	1.4000	2.9000	0.0 B	26.0000	0.0	270.0000	2033.6389	612.0000	4609.5781
CFS 5	82368.0000	1.0000	3.0000	0.0 B	23.0000	0.0	530.0000	2851.3994	801.0000	4305.3785
CFS 5	92568.0000	1.0000	2.4000	0.0 B	19.0000	0.0	318.0000	1710.8396	526.0000	2829.8754
CFS 5	102368.0000	1.8000	2.5000	0.0 B	14.0000	0.0	610.0000	5907.2344	677.0000	6556.0625
CFS 5	112068.0000	16.0000	3.1000	560.0000	2.0000	0.0	394.0000	38515.5117	714.0000	61461.1054
CFS 5	121868.0000	11.0000	3.2000	470.0000	2.0000	0.0	273.0000	16156.1328	320.0000	18937.5898
CFS 5	12263.0000	18.8000	3.2000	440.0000	5.0000	0.0	154.0000	15576.1602	155.0000	19723.0566
CFS 5	22669.0000	8.0000	2.9500	560.0000	0.5000	0.0	283.7500	12212.5977	720.0000	30988.7930
CFS 5	40369.0000	49.8000	2.7000	0.0 B	6.5000	0.0	121.0000	32418.7812	132.0000	35365.9453
CFS 5	50769.0000	8.1000	3.4000	0.0 B	21.5000	0.0	191.6000	8349.5391	403.7598	17596.7812
CFS 5	52169.0000	9.2000	0.0 B	750.0000	20.0000	0.0	189.6000	9384.4375	159.0000	7699.5586

NORTH BRANCH, STEYER, MD.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (C)
CFS 6	31368.0000	1030.0000	3.1000	0.0 B	2.0000	0.0	37.0000	205031.6875	0.0 B	0.0 B
CFS 6	32768.0000	237.0000	2.6000	0.0 B	12.0000	0.0	45.0000	57377.6797	16.0000	20400.9531
CFS 6	41068.0000	126.0000	2.4000	0.0 B	12.0000	0.0	88.0000	59653.4297	171.0000	115917.4375
CFS 6	50168.0000	62.0000	3.2000	0.0 B	16.0000	0.0	126.0000	42028.5352	323.0000	107739.8125
CFS 6	51568.0000	289.0000	0.0 B	0.0 B	17.0000	0.0	31.0000	48199.4062	68.0000	105727.6875
CFS 6	52768.0000	461.0000	3.8000	0.0 B	10.0000	0.0	70.0000	173612.5000	104.0000	257938.6250
CFS 6	61268.0000	191.0000	3.2000	0.0 B	16.0000	0.0	104.0000	106868.2500	135.0000	138723.2500
CFS 6	62668.0000	35.0000	3.2000	0.0 B	23.0000	0.0	212.0000	39019.5898	433.0000	81533.8750
CFS 6	71068.0000	11.0000	3.0000	0.0 B	28.0000	0.0	280.0000	16570.3906	522.0000	30891.5453
CFS 6	72468.0000	6.9000	2.5000	0.0 B	28.0000	0.0	360.0000	13363.9102	496.0000	18412.5000
CFS 6	80768.0000	89.0000	0.0 B	0.0 B	24.0000	0.0	180.0000	86187.5625	283.0000	135506.0000
CFS 6	82868.0000	9.2000	2.8000	0.0 B	23.0000	0.0	593.0000	29351.1172	774.0000	38309.8506
CFS 6	91168.0000	40.0000	2.4000	0.0 B	0.0 B	0.0	353.0000	75965.5625	366.0000	78763.1875
CFS 6	92568.0000	8.6000	2.3000	0.0 B	20.0000	0.0	273.0000	12631.1562	524.0000	24244.4180
CFS 6	100768.0000	14.0000	0.0 B	0.0 B	13.0000	0.0	272.0000	20487.0312	923.0000	69520.3125
CFS 6	102368.0000	17.0000	2.7000	0.0 B	14.0000	0.0	245.0000	22407.6914	238.0000	21767.4727
CFS 6	110668.0000	19.0000	2.6000	0.0 B	12.0000	0.0	228.0000	23306.1523	440.0000	44976.7852
CFS 6	112068.0000	288.0000	3.0000	263.0000	2.0000	0.0	102.0000	158042.8125	383.0000	593435.3750
CFS 6	120468.0000	222.0000	5.0000	345.0000	5.0000	0.0	105.0000	125407.7500	154.0000	183731.3750
CFS 6	121868.0000	240.0000	3.2000	280.0000	1.0000	0.0	84.0000	126537.3625	308.0000	463971.0625
CFS 6	10369.0000	301.0000	2.8000	278.0000	0.0	0.0	145.0000	234810.0000	177.0000	286630.1875
CFS 6	12269.0000	470.0000	2.9000	260.0000	1.5000	0.0	87.0000	219988.1250	142.0000	485491.0625
CFS 6	20669.0000	241.0000	3.2000	160.0000	1.0000	0.0	129.0000	167259.7500	152.0000	197080.0625
CFS 6	21669.0000	70.0000	2.9000	490.0000	0.5000	0.0	162.3100	61125.9180	407.0000	153276.1250
CFS 6	31269.0000	99.0000	3.3000	0.0 B	0.0	0.0	108.7800	57938.3867	216.0000	115045.8750
CFS 6	40369.0000	500.0000	3.1000	0.0 B	7.5000	0.0	72.6000	195293.9375	69.0000	185609.9375
CFS 6	41669.0000	154.0000	2.9000	540.0000	14.0000	0.0	154.7800	128238.2500	260.0000	215415.1250
CFS 6	50769.0000	85.0000	3.3000	0.0 B	23.0000	0.0	116.7000	53366.8828	203.5000	93060.5000
CFS 6	51469.0000	208.0000	3.0500	3.4500	12.5000	0.0	70.2000	78556.5625	247.3000	276738.5000
CFS 6	52169.0000	102.0000	0.0 B	650.0000	20.5000	0.0	214.5000	117928.4375	93.9000	51628.5352
CFS 6	52769.0000	64.0000	2.7000	820.0000	21.5000	0.0	178.5000	61461.0859	47.0000	16183.0312

STONY RIVER, MT. STORM, W. VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS B	31368.0000	391.0000	4.4000	0.0 B	4.0000	0.0 N	4.9000	10307.5391	0.0 B	0.0 B
CFS B	32768.0000	172.0000	4.2000	0.0 B	14.0000	0.0 N	4.2000	3886.5100	0.0 N	0.0 B
CFS B	41068.0000	88.0000	4.5000	0.0 B	14.0000	0.0 N	4.6000	2177.8223	40.0000L	0.0 B
CFS B	50168.0000	9.7000	6.1000	0.0 B	16.0000	5.9000	2.3000	120.0277	265.0000	13829.2852
CFS B	51568.0000	46.0000	0.0 B	0.0 B	17.0000	6.9000	1.5000	371.2197	42.0000	10394.1562
CFS B	52768.0000	721.0000	5.0000	0.0 B	14.0000	1.9000	4.2000	16291.7109	39.0000	151280.1875
CFS B	61268.0000	16.0000	5.4000	0.0 B	16.0000	2.1000	2.1000	180.7679	13.0000	1119.0356
CFS B	62668.0000	10.0000	6.6000	0.0 B	22.0000	0.0 B	0.0 B	0.0 B	0.0 B	0.0 B
CFS B	71068.0000	2.3000	5.6000	0.0 B	26.0000	0.0 B	2.6000	32.1724	0.0 N	0.0 B
CFS B	72468.0000	1.9000	6.8000	0.0 B	27.0000	0.0 B	14.3000	146.1745	16.0000	163.5514
CFS B	73768.0000	21.0000	0.0 B	0.0 B	25.0000	1.0000	5.4000	610.0918	22.0000	2485.5566
CFS B	82868.0000	46.0000	5.7000	0.0 B	18.0000	4.1000	9.6000	2375.8074	41.0000	10146.6758
CFS B	91168.0000	54.0000	5.2000	0.0 B	0.0 B	4.0000	7.4000	2149.8462	0.0 N	0.0 B
CFS B	92568.0000	3.3000	6.4000	0.0 B	18.0000	14.4000	0.6000	10.6524	0.0 N	0.0 B
CFS B	100968.0000	15.0000	0.0 B	0.0 B	11.0000	12.2000	4.8000	371.2197	0.0 N	0.0 B
CFS B	102368.0000	51.0000	3.0000	0.0 B	13.0000	0.0 N	1.9000	521.3213	15.0000	4115.6953
CFS B	110668.0000	65.0000	5.3000	0.0 B	10.0000	24.9000	8.2000	2867.5374	0.0 N	0.0 B
CFS B	112068.0000	203.0000	3.8000	115.0000	2.0000	1.9000	7.9000	8627.9023	41.0000	44777.7227
CFS B	120468.0000	230.0000	6.8000	95.0000	5.0000	3.3000	6.8000	8414.3164	29.0000	32172.3506
CFS B	121868.0000	259.0000	4.2000	100.0000	2.0000	2.4000	9.8000	13655.5117	12.0000	16721.0352
CFS B	10868.0000	158.0000	4.0000	78.0000	0.0	0.0 B	30.0000	25501.1914	23.0000	19550.9141
CFS B	12268.0000	151.0000	4.2000	120.0000	5.0000	0.0 B	21.7000	17628.6328	63.0000	51179.9141
CFS B	20569.0000	363.0000	4.0000	80.0000	6.0000	0.0 B	17.6000	34371.7148	23.0000	44917.6055
CFS B	22669.0000	100.0000	3.1500	110.0000	1.5000	2.1000	10.2200	5498.3555	333.0000	179153.8750
CFS B	31269.0000	88.0000	5.0000	0.0 B	0.0	2.1000	10.0000	4734.3945	12.0000	5681.2734
CFS B	40353.0000	225.0000	3.1500	0.0 B	8.0000	1.5800	4.9500	5951.9727	6.0000	7262.9561
CFS B	41669.0000	82.0000	4.8000	100.0000	14.0000	3.6800	2.1800	961.7283	5.0000	2205.7959
CFS B	50769.0000	62.0000	4.3500	0.0 B	21.0000	0.5200	4.8600	1621.1003	90.9000	30320.5820
CFS B	51969.0000	91.0000	4.5000	80.0000	13.5000	3.5900	1.9500	854.0304	38.4000	17820.6992
CFS B	54169.0000	93.0000	0.0 B	100.0000	18.0000	1.5400	5.8400	2921.9841	40.9000	20463.8545
CFS B	52769.0000	59.0000	4.7500	90.0000	19.0000	2.0500	4.6300	1469.6538	162.1000	51453.7656

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ABRAM CREEK, OAKMONT, W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (C)
CFS 16	31368.0000	241.0000	3.9000	0.0 B	2.0000	0.0	15.0000	19448.6914	0.0 B	0.0 B
CFS 16	32768.0000	123.0000	3.1000	0.0 B	12.0000	0.0	20.0000	13234.7930	30.0000	19852.1914
CFS 16	41068.0000	37.0000	3.2000	0.0 B	12.0000	0.0	21.0000	4180.2578	64.0000	12739.8359
CFS 16	50168.0000	18.0000	3.6000	0.0 B	16.0000	0.0	28.0000	2711.5193	114.0000	11039.7578
CFS 16	51568.0000	86.0000	0.0 B	0.0 B	18.0000	0.0	14.0000	6477.5156	52.0000	24059.3437
CFS 16	52768.0000	560.0000	4.4000	0.0 B	10.0000	0.0	16.0000	48204.7891	34.0000	117499.1250
CFS 16	61268.0000	33.0000	3.5000	0.0 B	22.0000	0.0	43.0000	7634.2148	90.0000	17358.9141
CFS 16	62868.0000	13.0000	3.7000	0.0 B	22.0000	0.0	53.0000	3706.8191	167.0000	11679.9766
CFS 16	71068.0000	4.0000	4.1000	0.0 B	25.0000	0.0	78.0000	1678.5591	226.0000	4863.5156
CFS 16	72468.0000	3.0000	3.7000	0.0 B	26.0000	0.0	72.0000	1510.7036	274.0000	5853.5727
CFS 16	80768.0000	5.4000	3.1000	0.0 B	25.0000	0.0	76.0000	2207.9509	240.0000	6972.4766
CFS 16	82668.0000	1.4000	3.6000	0.0 B	16.0000	0.0	171.0000	1287.9714	312.0000	2349.9829
CFS 16	91168.0000	4.3000	3.1000	0.0 B	0.0 B	0.0	151.0000	3493.2319	336.0000	7773.0195
CFS 16	92568.0000	1.3000	3.2000	0.0 B	17.0000	0.0	74.0000	517.5554	304.0000	2126.1743
CFS 16	100968.0000	3.1000	0.0 B	0.0 B	12.0000	0.0	133.0000	2361.2795	731.0000	12978.1602
CFS 16	102368.0000	3.9000	3.2000	0.0 B	12.0000	0.0	183.0000	3839.7048	300.0000	6294.5977
CFS 16	110668.0000	3.9000	3.1000	0.0 B	11.0000	0.0	118.0000	2475.8752	454.0000	9525.8242
CFS 16	112068.0000	28.0000	3.0000	335.0000	1.0000	0.0	91.0000	13708.2344	175.0000	26361.9922
CFS 16	120468.0000	160.0000	6.1000	245.0000	5.0000	0.0	24.0000	20659.1953	122.0000	105017.5625
CFS 16	121868.0000	18.0000	3.2000	310.0000	1.0000	0.0	63.0000	6100.9180	200.0000	19367.9961
CFS 16	10869.0000	84.0000	3.0000	275.0000	0.0	0.0	74.0000	33442.0742	124.0000	56038.0703
CFS 16	12269.0000	34.0000	3.0000	270.0000	0.0	0.0	50.0000	9145.9961	90.0000	16462.7969
CFS 16	20569.0000	64.0000	3.4000	190.0000	0.0	0.0	34.0000	11706.8711	178.0000	61288.9258
CFS 16	22669.0000	22.0000	3.3000	760.0000	0.5000	0.0	28.4000	3361.4224	220.0000	26035.1914
CFS 16	31269.0000	26.0000	3.6000	0.0 B	0.0	0.0	13.3000	1860.4033	113.0000	15806.4336
CFS 16	40369.0000	107.0000	3.8000	0.0 B	8.0000	0.0	19.8000	11398.0508	38.0000	21875.0664
CFS 16	41869.0000	58.0000	3.7500	210.0000	14.0000	0.0	19.1000	5959.3570	310.0000	96732.3125
CFS 16	50769.0000	21.0000	3.5000	0.0 B	21.5000	0.0	19.0000	2146.6196	3.0000	338.9394
CFS 16	51469.0000	20.0000	3.6000	260.0000	14.0000	0.0	23.4000	3650.8662	228.5000	35650.5625
CFS 16	52169.0000	71.0000	0.0 B	235.0000	19.0000	0.0	19.5000	7448.6016	13.6000	5194.9219
CFS 16	52769.0000	24.0000	3.7000	200.0000	18.5000	0.0	22.2000	2866.4631	482.0000	62235.8281

NORTH BRANCH, KITZMILLER, MD.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 18	31368.0000	2050.0000	4.9000	0.0 B	2.0000	0.0	21.0000	231608.8750	0.0 B	0.0 B
CFS 18	32768.0000	845.0000	2.9000	0.0 B	12.0000	0.0	28.0000	127290.6875	30.0000	136382.8750
CFS 18	41068.0000	338.0000	2.7000	0.0 B	12.0000	0.0	39.0000	70919.1250	84.0000	152748.8750
CFS 18	50168.0000	118.0000	3.2000	0.0 B	15.0000	0.0	48.0000	30472.3125	200.0000	130777.0000
CFS 18	51568.0000	693.0000	0.0 B	0.0 B	15.0000	0.0	19.0000	70838.4375	44.0000	164046.8750
CFS 18	52768.0000	2200.0000	3.0000	0.0 B	12.0000	0.0	24.0000	284063.6750	53.0000	527307.7500
CFS 18	61268.0000	354.0000	3.2000	0.0 B	22.0000	0.0	70.0000	133316.3125	117.0000	222828.7500
CFS 18	62668.0000	91.0000	3.4000	0.0 B	23.0000	0.0	100.0000	48957.4805	192.0000	93959.3125
CFS 18	71068.0000	28.0000	2.4000	0.0 B	20.0000	0.0	135.0000	20336.3945	296.0000	44585.4297
CFS 18	72468.0000	19.0000	3.2000	0.0 B	0.0 B	0.0	150.0000	15332.9922	256.0000	26168.3125
CFS 18	80768.0000	65.0000	3.1000	0.0 B	28.0000	0.0	77.0000	26926.8750	204.0000	71338.6875
CFS 18	82868.0000	26.0000	3.1000	0.0 B	19.0000	0.0	162.0000	22660.5547	190.0000	26577.1914
CFS 18	91168.0000	79.0000	2.7000	0.0 B	0.0 B	0.0	222.0000	94354.3750	333.0000	141531.5625
CFS 18	92568.0000	11.0000	2.4000	0.0 B	20.0000	0.0	163.0000	9646.3359	636.0000	37638.4648
CFS 18	100368.0000	25.0000	0.0 B	0.0 B	15.0000	0.0	210.0000	28244.9922	769.0000	103430.4375
CFS 18	102368.0000	27.0000	2.8000	0.0 B	14.0000	0.0	208.0000	30214.0703	200.0000	29051.9922
CFS 18	110668.0000	30.0000	2.7000	0.0 B	12.0000	0.0	163.0000	26308.1914	380.0000	61331.9844
CFS 18	112068.0000	495.0000	3.4000	240.0000	2.0000	0.0	69.0000	183753.8125	120.0000	319571.8750
CFS 18	120468.0000	430.0000	4.9000	320.0000	7.0000	0.0	59.0000	136490.5625	114.0000	263727.5000
CFS 18	121868.0000	270.0000	3.1000	240.0000	1.0000	0.0	49.0000	71177.3750	91.0000	132186.5625
CFS 18	10868.0000	205.0000	3.0000	255.0000	1.0000	0.0	74.0000	81614.5625	90.0000	99260.6375
CFS 18	12268.0000	354.0000	0.0 B	235.0000	2.0000	0.0	59.0000	112366.6250	56.0000	106653.0625
CFS 18	20569.0000	856.0000	3.3000	200.0000	2.0000	0.0	52.0000	242272.0625	59.0000	274885.5625
CFS 18	22569.0000	178.0000	3.0000	325.0000	1.0000	0.0	74.0000	70865.3125	212.0000	203019.5625
CFS 18	31269.0000	112.0000	3.2000	0.0 B	1.0000	0.0	60.0000	36153.5859	144.0000	86768.5625
CFS 18	40369.0000	1090.0000	3.2000	0.0 B	7.5000	0.0	39.0000	228703.5625	70.0000	410493.6250
CFS 18	41869.0000	330.0000	3.1000	460.0000	14.0000	0.0	52.0000	92320.7500	106.0000	188192.3125
CFS 18	50769.0000	157.0000	3.3500	0.0 B	18.5000	0.0	53.0000	44766.9609	128.7000	108707.6875
CFS 18	51469.0000	316.0000	3.2000	280.0000	13.5000	0.0	45.0000	76503.5625	235.0000	399518.6875
CFS 18	52169.0000	249.0000	0.0 B	280.0000	18.0000	0.0	37.0000	49565.9258	140.9000	188752.3750
CFS 18	52769.0000	114.0000	3.0500	400.0000	20.0000	0.0	41.0000	25146.1094	159.6000	97885.8125

THREEFORK RUN, EAST-VINDEX,MD.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 19	61268.0000	8.2000	3.3000	0.0 B	18.0000	0.0	80.0000	3529.2786	132.0000	5823.3066
CFS 19	71068.0000	0.8200	2.2000	0.0 B	23.0000	0.0	402.0000	1773.4026	704.0000	3105.7656
CFS 19	80768.0000	0.4400	2.5000	0.0 B	23.0000	0.0	553.0000	1309.0608	1000.0000	2367.1987
CFS 19	91168.0000	0.8500	2.5000	0.0 B	0.0 B	0.0	620.0000	2835.2593	1440.0000	6585.1172
CFS 19	100968.0000	0.2800	0.0 B	0.0 B	10.0000	0.0	600.0000	903.8394	3230.0000	4865.6660
CFS 19	110668.0000	0.4500	2.5000	0.0 B	11.0000	0.0	695.0000	1682.5745	1670.0000	4043.0651
MDwR 19	53168.0000	56.0000	3.5000	0.0 B	0.0 B	0.0	61.0000	4594.5156	1100.0000	82851.9375
MDwR 19	61468.0000	4.8000	3.1000	0.0 B	0.0 B	0.0	34.0000	10243.5117	250.0000	75319.9375
MDwR 19	62868.0000	1.4000	3.0000	0.0 B	0.0 B	0.0	144.0000	3770.3025	120.0000	3098.8787
MDwR 19	71568.0000	1.1000	3.2000	0.0 B	0.0 B	0.0	218.0000	1641.9751	400.0000	3012.7588
MDwR 19	80968.0000	0.3300	3.2000	0.0 B	0.0 B	0.0	196.0000	1159.9270	115.0000	680.5693
MDwR 19	82368.0000	0.2000	2.9000	0.0 B	0.0 B	0.0	442.0000	784.7263	240.0000	426.0957
MDwR 19	91628.0000	0.2000	2.8000	0.0 B	0.0 B	0.0	940.0000	1011.4392	1700.0000	1829.1987
MDwR 19	92768.0000	0.1800	3.0000	0.0 B	0.0 B	0.0	920.0000	989.9192	1600.0000	1721.5986
MDwR 19	101168.0000	0.2600	3.1000	0.0 B	0.0 B	0.0	1400.0000	1355.7593	1600.0000	1549.4392
MDwR 19	102568.0000	0.3500	3.0000	0.0 B	0.0 B	0.0	1150.0000	1608.6187	1400.0000	1958.3184
MDwR 19	110868.0000	1.3300	3.4000	0.0 B	0.0 B	0.0	1250.0000	2353.7493	1050.0000	1977.1492
CFS 19	10569.0000	0.0 B	2.8000	400.0000	0.0	0.0	305.0000	2182.3965	420.0000	3005.2671
CFS 19	20569.0000	14.3000	3.0000	290.0000	2.0000	0.0	151.0000	0.0 B	171.0000	0.0 B
CFS 19	31269.0000	4.8000	3.3000	0.0 B	2.0000	0.0	95.0000	7308.7266	54.0000	4154.4336
CFS 19	41669.0000	13.9000	3.2000	420.0000	13.0000	0.0	122.1000	3153.1089	242.0000	6249.4023
CFS 19	51469.0000	4.0000	2.9000	400.0000	12.5000	0.0	86.1100	6439.4727	15.0000	1121.7297
CFS 19	52769.0000	2.0000	2.7500	725.0000	17.0000	0.0	95.5500	2056.2346	563.0000	12546.1523
MDwR19	10369.0000	5.9700	3.8000	0.0 B	0.0 B	0.0	187.7800	2020.5125	0.0 B	0.0 B
MDwR19	11769.0000	4.0300	3.1500	0.0 B	0.0 B	0.0	115.0000	3693.6362	150.0000	4817.7852
MDwR19	13169.0000	18.8500	3.5000	0.0 B	0.0 B	0.0	150.0000	3252.2070	290.0000	6287.5977
MDwR19	21469.0000	6.0100	3.2500	0.0 B	0.0 B	0.0	74.0000	7504.5547	90.0000	9127.1602
MDwR19	30459.0000	5.0700	3.4000	0.0 B	0.0 B	0.0	102.0000	3298.0461	200.0000	6466.7539
MDwR19	31869.0000	7.3400	3.4000	0.0 B	0.0 B	0.0	129.0000	3518.0787	210.0000	5726.0781
MDwR19	40769.0000	16.3900	3.3000	0.0 B	0.0 B	0.0	100.0000	3048.7180	32.0000	1263.6538
MDwR19	42269.0000	9.4100	3.4000	0.0 B	0.0 B	0.0	90.0000	7936.0352	117.0000	10316.8437
MDwR19	51969.0000	3.3300	3.1500	0.0 B	0.0 B	0.0	106.0000	5366.3320	152.0000	7695.1172
							139.0000	2490.2390	220.0000	3941.3857

LOSTLAND RUN

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 21A	82868.0000	0.1000	3.9000	0.0 B	15.0000	0.0	98.0000	52.7240	244.0000	131.2715
CFS 21A	92568.0000	0.1000	2.7000	0.0 B	17.0000	0.0	130.0000	69.9400	352.0000	189.3759
CFS 21A	102568.0000	0.1000	3.4000	0.0 B	10.0000	0.0	123.0000	66.1740	123.0000	66.1740
CFS 21A	112068.0000	16.0000	3.4000	145.0000	2.0000	0.0	17.0000	1463.3576	62.0000	5336.9570
CFS 21A	121868.0000	14.0000	3.3000	250.0000	1.0000	0.0	41.0000	3088.1189	47.0000	3540.0388
CFS 21A	12269.0000	12.2000	3.3000	125.0000	2.0000	0.0	27.0000	1772.1716	61.0000	4003.7952
CFS 21A	22669.0000	6.8000	3.4000	160.0000	1.0000	0.0	21.6000	790.2136	103.0000	3766.1504
CFS 21A	40369.0000	25.0000	3.5000	0.0 B	7.0000	0.0	14.3000	2000.2834	26.0000	3636.8752
CFS 21A	50769.0000	6.4000	3.8500	0.0 B	14.5000	0.0	16.1000	554.3547	6.0600	208.6578
CFS 21A	52169.0000	5.0000	0.0 B	160.0000	15.5000	0.0	14.6000	392.7397	39.4000	1059.8554

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ELKLICK RUN, MANOR HILLS,W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
MDWR23A	80968.0000	0.2200	7.2000	0.0 B	0.0 B	0.0 B	36.0000	42.6096	270.0000	319.5718
MDWR23A	82368.0000	0.1500	7.5000	0.0 B	0.0 B	0.0 B	16.0000	12.9120	0.0 B	0.0 B
MDWR23A	91668.0000	0.1700	7.4000	0.0 B	0.0 B	0.0 B	14.0000	12.8044	380.0000	347.5476
MDWR23A	92768.0000	0.1300	7.4000	0.0 B	0.0 B	0.0 B	7.0000	4.8958	220.0000	153.8680
MDWR23A	101168.0000	0.2700	7.5000	0.0 B	0.0 B	0.0 B	12.0000	17.4312	250.0000	363.1497
MDWR23A	102568.0000	0.3100	7.6000	0.0 B	0.0 B	0.0 B	13.0000	21.6814	330.0000	550.3739
MDWR23A	110868.0000	1.0000	7.4000	0.0 B	0.0 B	0.0 B	14.0000	75.3200	216.0000	1162.0796
MDWR23A	10369.0000	1.4100	6.3000	0.0 B	0.0 B	0.0 B	28.0000	212.4023	170.0000	1289.5854
MDWR23A	11769.0000	0.9000	6.2500	0.0 B	0.0 B	0.0 B	15.0000	72.6300	200.0000	968.3957
MDWR23A	13169.0000	6.4500	5.5500	0.0 B	0.0 B	0.0 B	26.0000	902.2256	110.0000	3817.1066
MDWR23A	21469.0000	3.6200	5.2000	0.0 B	0.0 B	0.0 B	26.0000	506.3652	180.0000	3505.6055
MDWR23A	30469.0000	2.4200	5.7000	0.0 B	0.0 B	0.0 B	27.0000	351.5288	150.0000	1952.9390
MDWR23A	31869.0000	3.0000	4.6000	0.0 B	0.0 B	0.0 B	36.0000	581.0393	23.0000	371.2155
MDWR23A	40769.0000	5.8500	4.0000	0.0 B	0.0 B	0.0 B	50.0000	1573.6494	95.0000	2989.9341
MDWR23A	42269.0000	4.1400	4.2000	0.0 B	0.0 B	0.0 B	40.0000	890.9270	132.0000	2940.0593
MDWR23A	51569.0000	1.6300	4.5500	0.0 B	0.0 B	0.0 B	24.0000	210.4655	140.0000	1227.7151

SAVAGE RIVER, BLOOMINGTON, MO.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (C)
CFS 28	62619.0000	67.0000	6.9000	0.0 B	16.0000	5.8000	1.2000	432.5515	8.0000	2883.6777
CFS 28	71068.0000	84.0000	5.1000	0.0 B	15.0000	12.7000	1.7000	768.2637	52.0000	23499.8359
CFS 28	72469.0000	78.0000	5.4000	0.0 B	14.0000	11.2000	4.7000	1972.3074	0.0 N	0.0 B
CFS 28	80768.0000	44.0000	6.0000	0.0 B	16.0000	9.6000	12.9000	3053.6873	22.0000	5207.8356
CFS 28	82858.0000	74.0000	7.0000	0.0 B	12.0000	32.3000	1.0000	398.1199	41.0000	16322.9141
CFS 28	91168.0000	59.0000	6.6000	0.0 B	0.0 B	10.2000	1.9000	603.0977	0.0 N	0.0 B
CFS 28	92568.0000	97.0000	6.3000	0.0 B	14.0000	10.6000	0.3000	156.5579	20.0000	10437.1953
CFS 28	100968.0000	65.0000	0.0 B	0.0 B	13.0000	9.1000	1.7000	594.4893	0.0 N	0.0 B
CFS 28	102368.0000	64.0000	5.6000	0.0 B	15.0000	8.2000	7.7000	2651.2625	0.0 N	0.0 B
CFS 28	110768.0000	69.0000	6.6000	0.0 B	13.0000	23.4000	4.4000	1633.3665	50.0000	18560.9844
CFS 28	112068.0000	10.3000	6.1000	310.0000	0.0	1.0000	39.4000	2119.7190	191.0000	10275.7969
CFS 28	120468.0000	105.0000	6.4000	185.0000	6.0000	6.6000	4.5000	2542.0496	61.0000	34458.8554
CFS 28	121868.0000	102.0000	0.0 B	88.0000	3.0000	2.6000	4.9000	2688.9226	0.0 N	0.0 B
CFS 28	10868.0000	103.0000	6.5500	94.0000	-1.0000	16.0100	9.6750	5361.3008	16.0000	8866.2383
CFS 28	12269.0000	100.0000	6.4000	95.0000	1.5000	4.8500	12.8100	6891.7734	28.0000	15063.9922
CFS 28	20569.0000	250.0000	6.7000	73.0000	1.0000	4.3700	37.1500	51965.3945	73.0000	102112.3125
CFS 28	22969.0000	46.0000	6.5000	110.0000	0.5000	9.9800	2.2700	561.7793	33.0000	8166.8359
CFS 28	31269.0000	11.0000	6.7000	0.0 B	-0.5000	9.4500	2.2200	131.3795	145.0000	8581.0937
CFS 28	40369.0000	56.0000	6.7000	0.0 B	7.5000	4.2000	5.5000	1657.0388	108.0000	32538.2148
CFS 28	41668.0000	16.0000	6.5000	280.0000	10.5000	5.7800	6.5400	562.9629	61.0000	5250.8789
CFS 28	50769.0000	14.0000	6.8500	0.0 B	15.5000	7.1500	2.9200	219.9343	37.9000	2854.6265
CFS 28	51469.0000	74.0000	6.4000	135.0000	11.5000	13.3300	1.9500	776.3335	40.9000	16283.0977
CFS 28	52169.0000	64.0000	0.0 B	120.0000	16.0000	15.8900	14.5900	5023.6250	4.5000	1549.4392
CFS 28	52769.0000	34.0000	6.9000	105.0000	14.8000	12.8100	4.6300	846.9192	25.6000	4719.3320

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SAVAGE RIVER, GAGING STATION

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (C)
CFS 28A	50168.0000	14.0000	6.6000	0.0 B	12.0000	14.7000	0.0 N	0.0 B	237.0000	17850.8320
CFS 28A	51568.0000	18.0000	0.0 B	0.0 B	10.0000	16.8000	0.0 N	0.0 B	40.0000	3873.5991
CFS 28A	52768.0000	707.0000	6.4000	0.0 B	11.0000	9.5000	2.5000	9509.1445	36.0000	136931.6675
CFS 28A	61268.0000	142.0000	9.4000	0.0 B	24.0000	1.8000	3.0000	2291.8792	13.0000	9931.4727
CFS 28A	62668.0000	67.0000	6.9000	0.0 B	10.0000	6.1000	2.0000	720.9194	333.0000	120033.0625
CFS 28A	71068.0000	84.0000	5.7000	0.0 B	10.0000	11.3000	3.5000	1581.7197	35.0000	15817.1553
CFS 28A	72468.0000	78.0000	7.0000	0.0 B	14.0000	9.7000	4.8000	2014.2710	31.0000	13008.8359
CFS 28A	80768.0000	44.0000	6.4000	0.0 B	16.0000	9.2000	43.0000	10178.9570	44.0000	10415.6758
CFS 28A	82868.0000	74.0000	6.4000	0.0 B	11.0000	21.5000	1.4000	557.3674	265.0000	105501.7500
CFS 28A	91168.0000	59.0000	6.5000	0.0 B	0.0 B	75.3000	3.3000	1047.4854	41.0000	13014.2148
CFS 28A	92568.0000	97.0000	6.4000	0.0 B	11.0000	11.5000	2.0000	1043.7197	0.0 N	0.0 B
CFS 28A	100968.0000	65.0000	0.0 B	0.0 B	12.0000	12.2000	1.9000	664.4292	77.0000	26926.8750
CFS 28A	102368.0000	64.0000	5.7000	0.0 B	16.0000	16.5000	1.4000	482.0476	0.0 N	0.0 B
CFS 28A	110668.0000	69.0000	6.1000	0.0 B	12.0000	22.4000	3.9000	1447.7566	18.0000	6681.9531
CFS 28A	112068.0000	10.0000	6.7000	80.0000	6.0000	19.9000	2.0000	107.6000	17.0000	914.5996
CFS 28A	120468.0000	105.0000	6.7000	93.0000	6.0000	21.0000	6.3000	3558.8689	12.0000	6778.7969
CFS 28A	121868.0000	102.0000	6.3000	76.0000	4.0000	36.4000	2.0000	1037.5145	9.0000	4936.8359
CFS 28A	10869.0000	103.0000	6.3000	55.0000	0.0	10.6700	8.2240	4557.2461	34.0000	18840.7539
CFS 28A	12259.0000	100.0000	6.3500	85.0000	2.0000	8.2500	16.7500	9011.4922	0.0 N	0.0 B
CFS 28A	20569.0000	260.0000	6.6000	65.0000	1.5000	7.7600	35.1000	49223.7383	11.0000	15386.7930
CFS 28A	22869.0000	46.0000	6.5500	70.0000	1.5000	12.6000	2.8400	702.8428	61.0000	15096.2734
CFS 28A	31269.0000	11.0000	6.7500	0.0 B	1.0000	16.8000	2.7800	164.5203	88.0000	5207.8359
CFS 28A	40369.0000	56.0000	6.8500	0.0 B	8.0000	10.5000	2.2000	662.8154	0.0 N	0.0 B
CFS 28A	41669.0000	16.0000	7.2000	100.0000	8.0000	9.9300	1.0000	93.8271	23.0000	1979.8359
CFS 28A	50769.0000	14.0000	6.8000	0.0 B	10.5000	13.2800	1.9500	146.3739	0.0 N	0.0 B
CFS 28A	51469.0000	74.0000	6.5500	70.0000	12.0000	12.3000	2.9300	1166.4910	31.8000	12660.2070
CFS 28A	52169.0000	64.0000	0.0 B	80.0000	16.0000	12.3000	0.9700	333.9900	9.1000	3133.3101
CFS 28A	52769.0000	34.0000	5.8000	80.0000	16.0000	12.8100	0.0 N	0.0 B	119.7000	21895.5195

NORTH BRANCH, BARNUM, W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (C)
CFS 238	52768.0000	2670.0000	3.9000	0.0 B	13.0000	0.0	28.0000	402208.6875	66.0000	948063.4375
CFS 238	61268.0000	385.0000	3.4000	0.0 B	24.0000	0.0	62.0000	128420.5625	135.0000	279625.4375
CFS 238	62668.0000	112.0000	3.4000	0.0 B	25.0000	0.0	91.0000	54832.9414	200.0000	120511.9375
CFS 238	71068.0000	34.0000	3.2000	0.0 B	29.0000	0.0	134.0000	24511.2734	322.0000	58900.2266
CFS 238	72468.0000	25.0000	4.9000	0.0 B	28.0000	0.0	175.0000	23537.4922	263.0000	35373.4883
CFS 238	80769.0000	72.0000	3.0000	0.0 B	28.0000	0.0	110.0000	42609.5820	569.0000	259143.6875
CFS 238	82869.0000	28.0000	3.2000	0.0 B	19.0000	0.0	165.0000	24855.5937	191.0000	28772.2305
CFS 238	91168.0000	72.0000	2.7000	0.0 B	0.0 B	0.0	142.0000	55005.0977	275.0000	106523.9375
CFS 238	92568.0000	16.0000	2.7000	0.0 B	20.0000	0.0	136.0000	11706.8750	366.0000	31677.4238
CFS 238	100968.0000	36.0000	0.0 B	0.0 B	13.0000	0.0	130.0000	25178.3945	538.0000	104199.8125
CFS 238	102368.0000	36.0000	3.1000	0.0 B	14.0000	0.0	131.0000	25372.0742	254.0000	49194.7070
CFS 238	110868.0000	36.0000	2.8000	0.0 B	12.0000	0.0	184.0000	35637.1094	346.0000	67013.2500
CFS 238	112068.0000	520.0000	3.0000	255.0000	2.0000	0.0	66.0000	184641.5000	133.0000	372080.6875
CFS 238	120468.0000	412.0000	3.4000	325.0000	7.0000	0.0	70.0000	155159.1250	122.0000	270420.2500
CFS 238	121868.0000	263.0000	3.2000	240.0000	0.0	0.0	68.0000	96215.8750	119.0000	168377.8125
CFS 238	10869.0000	244.0000	2.0000	260.0000	0.0	0.0	89.0000	116832.0000	90.0000	118144.7500
CFS 238	12269.0000	397.0000	3.1000	220.0000	0.0	0.0	58.0000	123879.5125	67.0000	143102.5625
CFS 238	20569.0000	918.0000	3.3000	195.0000	3.0000	0.0	55.0000	271635.9375	76.0000	385229.1875
CFS 238	22669.0000	248.0000	2.0000	406.0000	1.5000	0.0	78.0000	98733.6875	165.0000	246834.3125
CFS 238	31269.0000	101.0000	3.6000	0.0 B	2.0000	0.0	55.5000	48072.4727	138.0000	119532.7500
CFS 238	40369.0000	1120.0000	3.2500	0.0 B	7.0000	0.0	34.7000	209088.1875	85.0000	512175.7500
CFS 238	41669.0000	356.0000	3.1500	440.0000	13.5000	0.0	58.8500	112733.3125	38.0000	72780.5625
CFS 238	50769.0000	176.0000	3.0000	0.0 B	21.0000	0.0	52.5200	49730.1055	84.8000	80295.3750
CFS 238	51469.0000	338.0000	3.1500	355.0000	14.0000	0.0	38.0300	69155.2500	266.0000	483704.9375
CFS 238	52159.0000	291.0000	0.0 B	300.0000	20.0000	0.0	35.0100	54810.9257	68.2000	106772.5000
CFS 238	52769.0000	144.0000	3.2500	365.0000	21.0000	0.0	49.4900	38340.8711	203.4500	157616.6875

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PINE SWAMP, HAMPSHIRE, W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (C)
CFS 25	61268.0000	3.8000	2.8000	0.0 B	22.0000	0.0	404.0000	8259.3672	765.0000	15639.6484
CFS 25	71068.0000	0.8400	2.2000	0.0 B	24.0000	0.0	574.0000	2594.0198	1480.0000	6688.4102
CFS 25	80768.0000	0.6400	2.6000	0.0 B	26.0000	0.0	728.0000	2506.6489	1513.0000	5209.5566
CFS 25	91169.0000	0.5000	2.4000	0.0 B	0.0 B	0.0	863.0000	2739.3337	1560.0000	5286.2148
CFS 25	100968.0000	0.2600	0.0 B	0.0 B	14.0000	0.0	840.0000	1174.9910	4076.0000	5701.5039
CFS 25	110668.0000	0.4100	2.4000	0.0 B	12.0000	0.0	972.0000	2144.0366	2172.0000	4790.4922
CFS 25	120468.0000	2.3000	2.1000	1125.0000	7.0000	0.0	470.0000	5815.7734	900.0000	11136.5937
CFS 25	10869.0000	0.5000	2.7000	1950.0000	0.0	0.0	609.5298	1639.6348	1242.0000	3340.9752
CFS 25	20569.0000	2.5000	2.8000	200.0000	1.0000	0.0	490.7100	6600.0469	466.0000	6267.6553
CFS 25	31269.0000	1.8000	2.8500	0.0 B	1.0000	0.0	280.8298	2719.5544	993.0000	9616.2031
CFS 25	41669.0000	5.0000	2.9000	725.0000	13.5000	0.0	158.0500	4251.5430	318.0000	8554.1953
CFS 25	51469.0000	1.5000	2.8000	800.0000	12.0000	0.0	273.9800	2211.0181	1533.0000	12371.3047
CFS 25	52769.0000	2.2000	3.0000	800.0000	17.0000	0.0	222.0000	2627.5911	444.0000	5255.1757

GEORGE'S CK, WESTERNPORT, MD.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 29A	22669.0000	30.0000	5.3000	470.0000	1.5000	2.6300	18.1600	2931.0212	333.0000	53746.1875
CFS 29A	31269.0000	22.0000	5.0000	0.0 B	0.0	2.1000	27.7500	3284.4890	682.0000	80721.4375
CFS 29A	40369.0000	72.0000	4.2000	0.0 B	8.0000	3.1500	8.8000	3408.7664	162.0000	62752.2969
CFS 29A	41669.0000	69.0000	4.7500	380.0000	12.0000	9.4500	4.9100	1822.6887	149.0000	55311.7383
CFS 29A	50769.0000	27.0000	6.5000	0.0 B	11.5000	2.0400	10.7000	1554.2815	166.7000	24214.8320
CFS 29A	51469.0000	32.0000	4.6000	490.0000	12.0000	5.1300	3.4100	587.0654	445.3999	76680.0000
CFS 29A	52169.0000	30.0000	0.0 B	600.0000	16.5000	7.1800	2.9200	471.2876	171.2000	27631.6719
CFS 29A	52769.0000	18.0000	4.6000	580.0000	16.0000	6.1500	6.4800	627.5229	256.0000	24791.0352

NORTH BRANCH, KEYSER, W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 33A	22669.0000	340.0000	4.7000	490.0000	4.5000	3.6800	38.5900	70588.7500	147.0000	268892.3125
CFS 33A	31269.0000	195.0000	6.5000	0.0 B	5.0000	44.1000	3.3300	3493.5015	0.0 B	0.0 B
CFS 33A	40369.0000	1230.0000	3.5000	0.0 B	8.0000	0.0 B	39.6000	262048.8750	114.0000	754383.3750
CFS 33A	41669.0000	530.0000	3.7500	420.0000	15.0000	0.0 B	65.4000	186481.5000	182.0000	518954.6875
CFS 33A	50769.0000	260.0000	6.1000	0.0 B	22.5000	4.6000	9.7300	13610.3164	227.3000	317947.0625
CFS 33A	51469.0000	490.0000	4.3500	500.0000	11.0000	3.0800	9.7500	25702.9414	195.4000	515113.3125
CFS 33A	52169.0000	600.0000	0.0 B	490.0000	20.0000	10.2500	3.4000	10975.1953	22.7000	73275.5625
CFS 33A	52769.0000	240.0000	5.6000	600.0000	21.7000	11.2800	2.3100	2982.6704	160.6000	207366.6250

UNNAMED TRIB., BARNUM, W.VA.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS M47	61269.0000	0.5000	2.6000	0.0 B	19.0000	0.0	667.0000	1794.2295	888.0000	2388.7153
CFS M47	71068.0000	0.1000	2.7000	0.0 B	24.0000	0.0	1975.0000	1062.5493	1983.0000	1066.8533
CFS M47	80768.0000	0.0 N	2.5000	0.0 B	23.0000	0.0	3070.0000	0.0 B	2378.0000	0.0 B

NORTH BRANCH, PINTO, MD.

SAMPLE	DATE	FLOW	PH	COND	TEMP	ALK T	AC TH	AC TH(Q)	SO4	SO4 (Q)
CFS 50	31368.0000	3560.0000	5.8000	0.0 B	3.0000	0.0 B	0.4000	7661.1172	0.0 B	0.0 B
CFS 50	32768.0000	1750.0000	4.4000	0.0 B	12.0000	0.0 N	9.4000	88500.9375	16.0000	150639.9375
CFS 50	41068.0000	576.0000	5.8000	0.0 B	16.0000	7.7000	2.7000	8366.9727	114.0000	353272.2500

LEGEND FOR BASIN SCHEMATICS

(Figures A-2 through A-7)

Symbol	Item
●	USGS Sampling Station
⊠	MBWR Sampling Station
⊕	W. Va. D.W.R. Sampling Station
□	W. Va. Pulp and Paper Co. Sampling Station
1, , ...	Station number
(0.0)	Drainage area square miles

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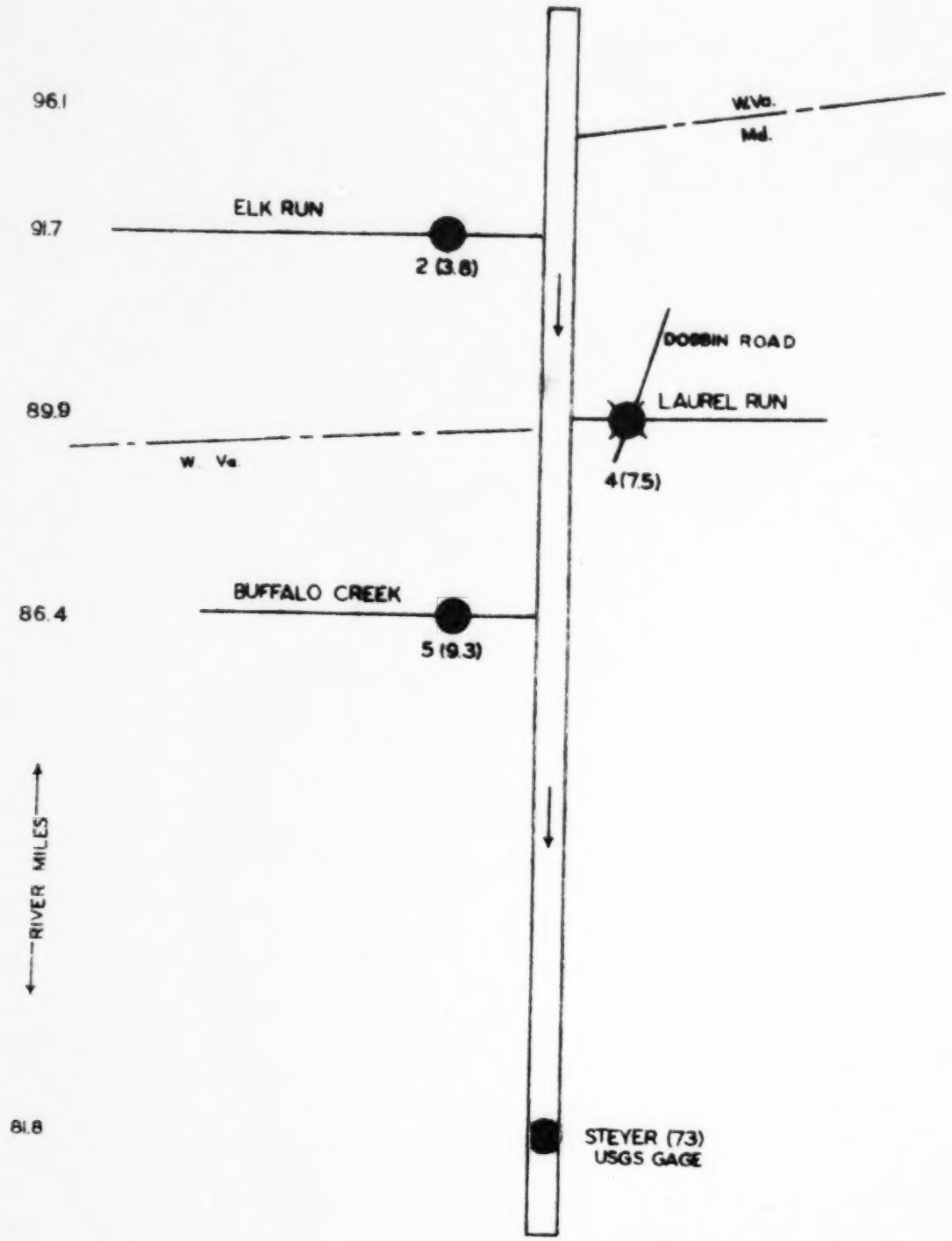
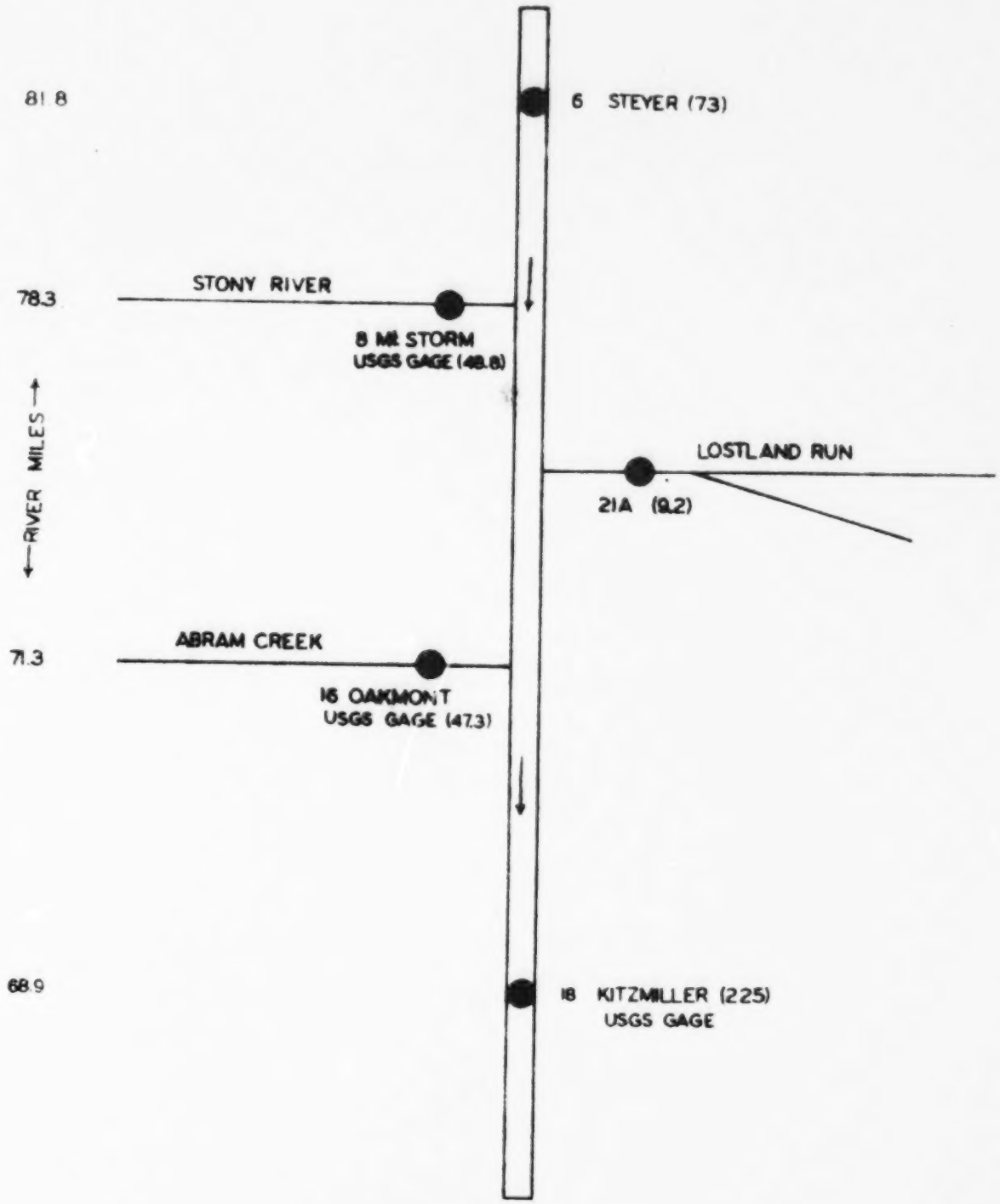
Figure A-1



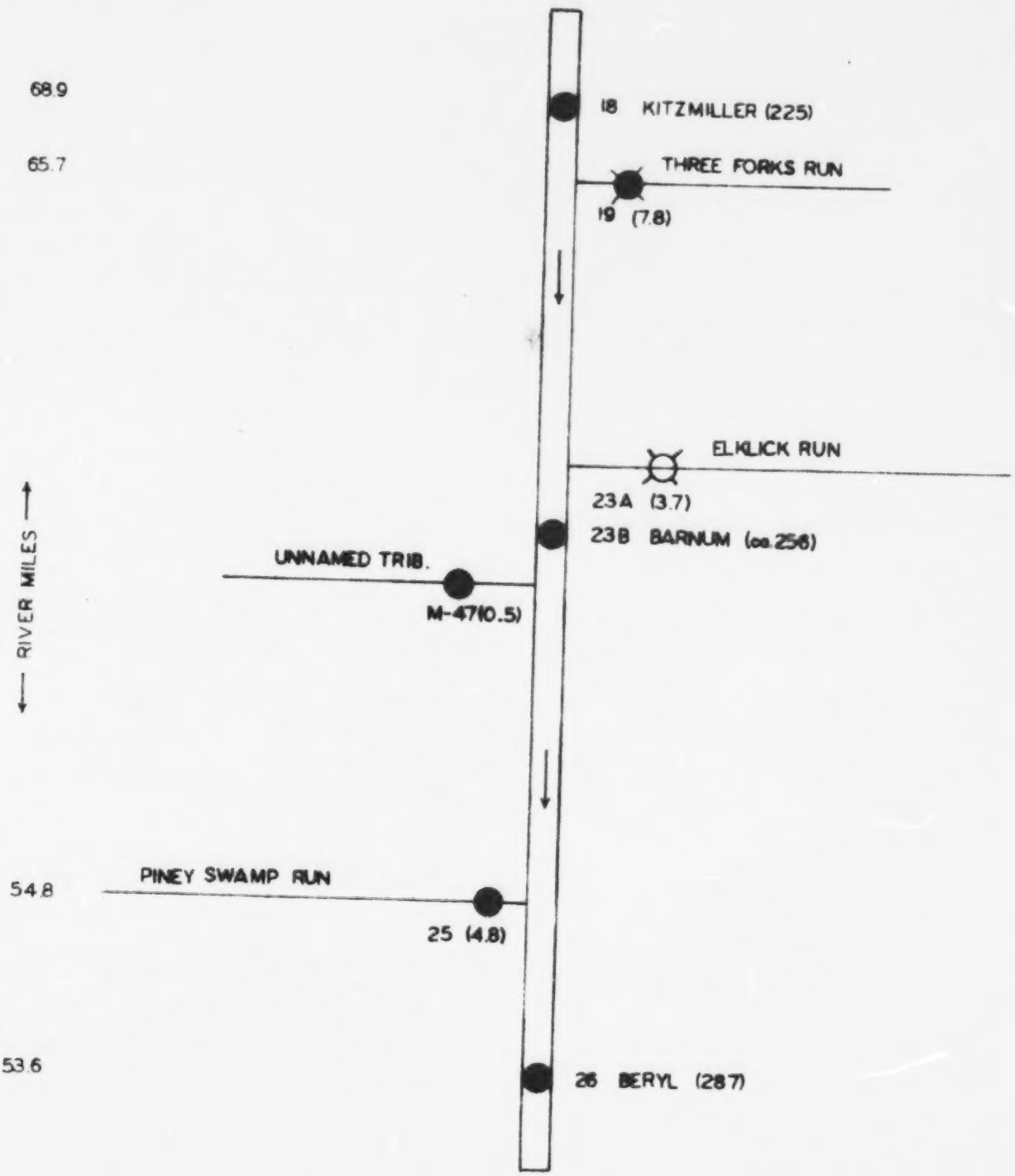
SCHEMATIC DIAGRAM
NORTH BRANCH
AREA A - ABOVE STEYER, Md

FIGURE A-2



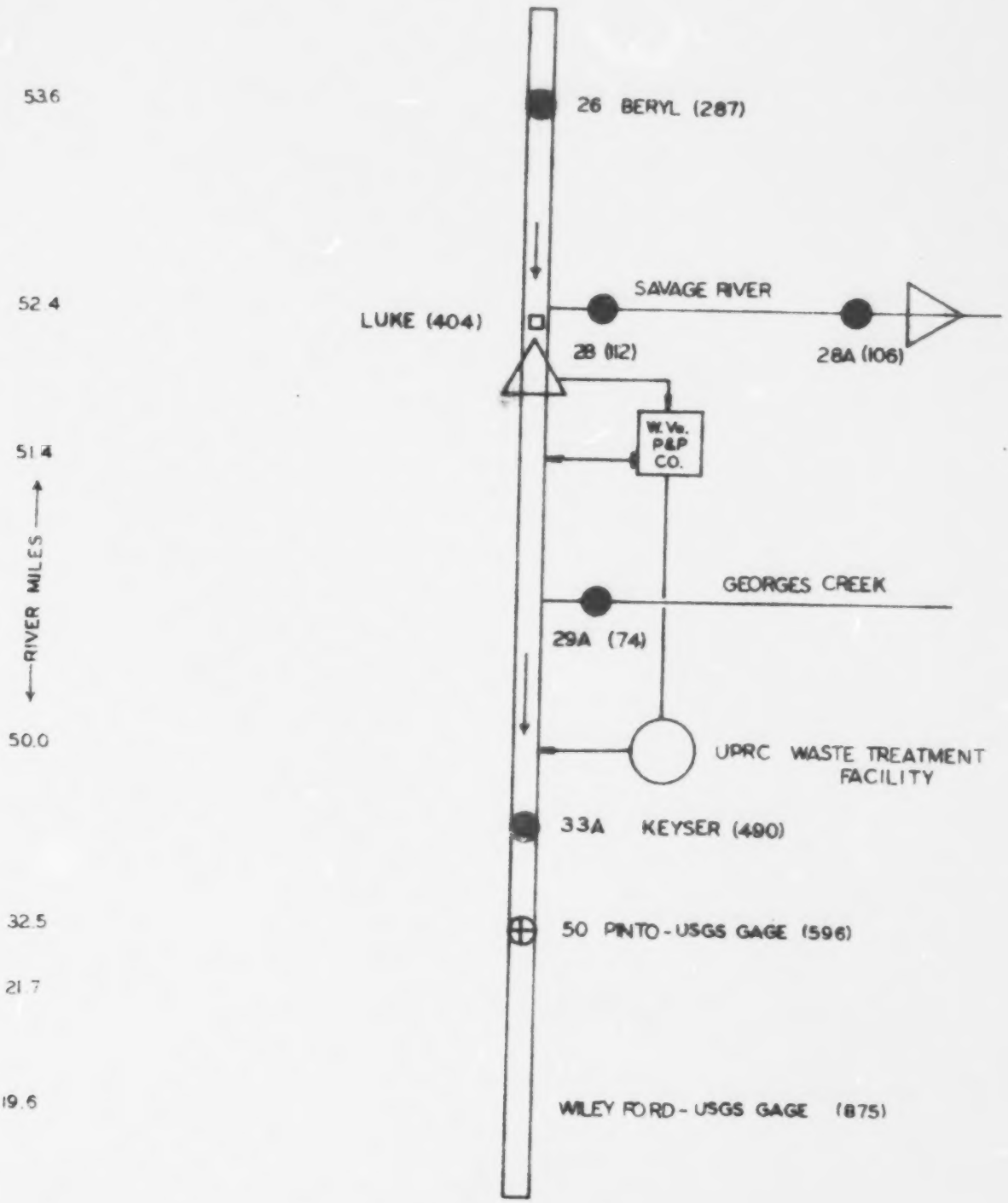
SCHEMATIC DIAGRAM
NORTH BRANCH
AREA B - BELOW STEYER, Md ABOVE KITZMILLER, Md.

FIGURE A-3



SCHEMATIC DIAGRAM
NORTH BRANCH
AREA C - BELOW KITZMILLER, Md. ABOVE BERYL, W.Va.

FIGURE A-4



SCHEMATIC DIAGRAM
NORTH BRANCH
AREA D - BELOW BERYL, W.Va. ABOVE WILEY FORD, Md.

FIGURE A-5